Quark Confinement and the Hadron Spectrum VII
Ponta Delgada, September 2nd-7th, 2006

Particle Production and Spectroscopy in ep-Collisions

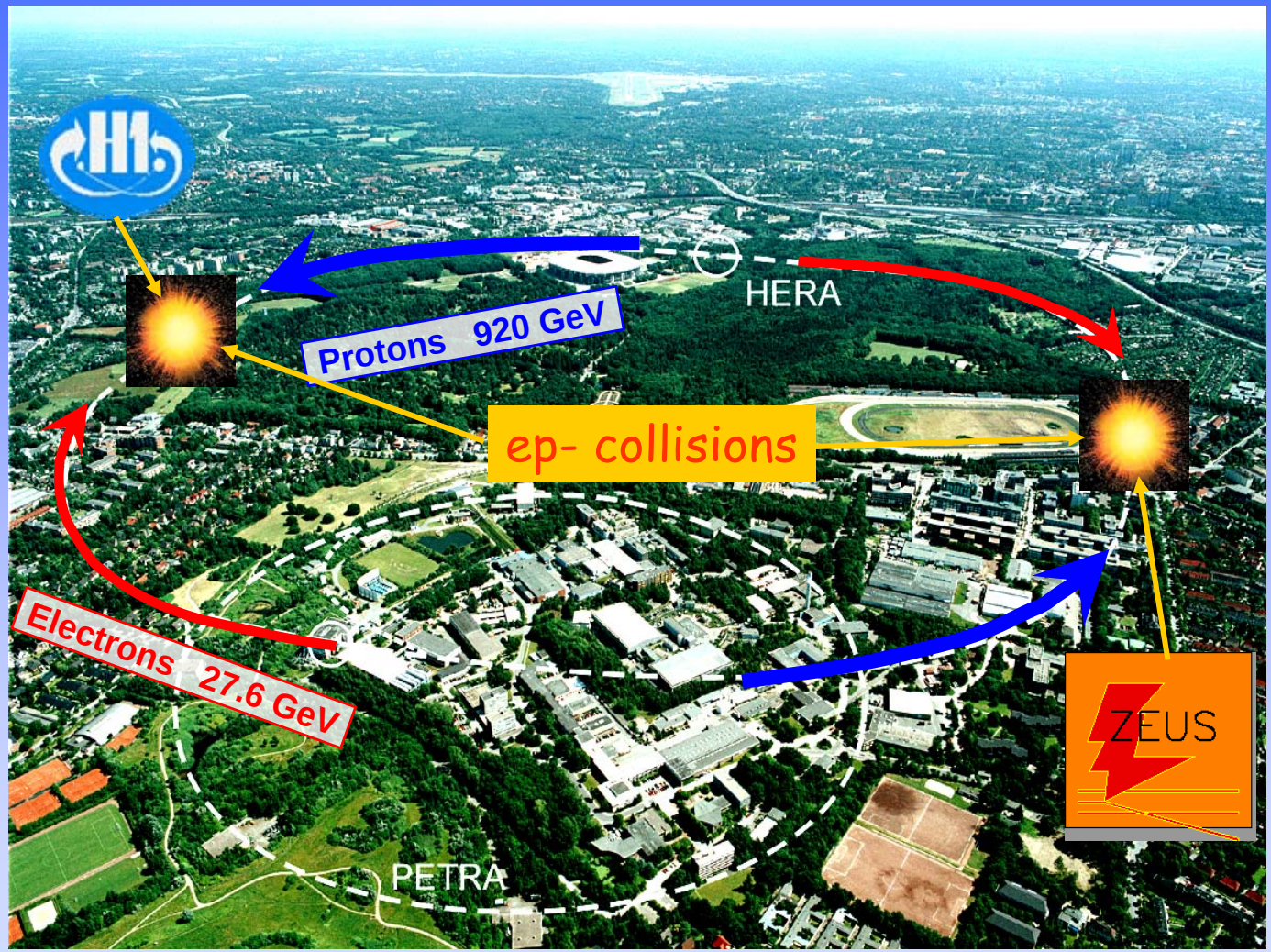
Karin Daum – Wuppertal
on behalf of the
H1 and ZEUS collaborations

Outline:

- HERA & kinematics at HERA
- Charged particle production
- Strange particle production
- Charm fragmentation
- Search for exotic baryons
- Conclusions

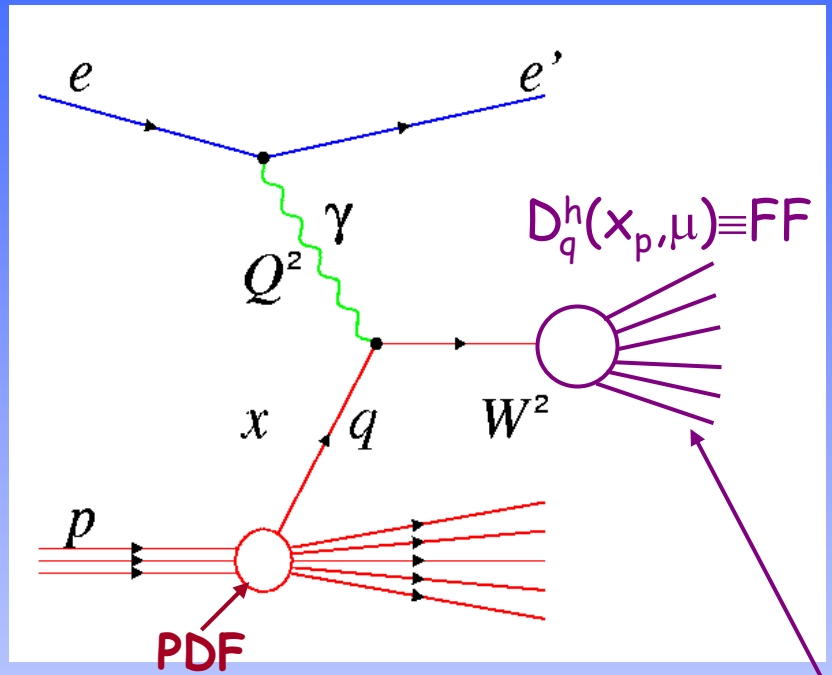
Lagoa do Fogo

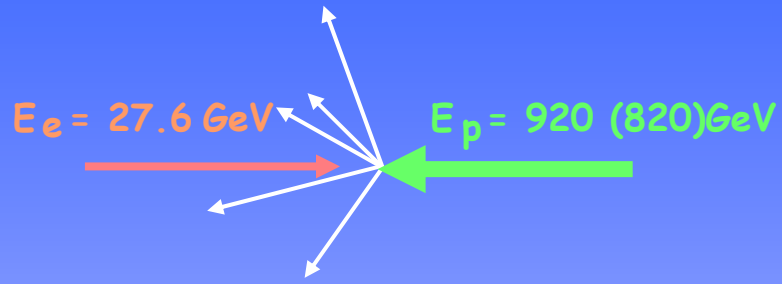
The HERA accelerator



DESY
Hamburg
Germany

HERA kinematics





ep-Kinematics:

$\sqrt{s}$ = 300-318 GeV (energy c.m.)

$Q^2=-q^2$ (photon virtuality)

$x=x_{BJ}$ (fraction of proton momentum carried by the struck quark)

2 kinematic regimes :
$Q^2 \cong 0$ GeV^2 : **Photoproduction (γp)**
$Q^2 > 1$ GeV^2 : **Electroproduction (DIS)**

Fragmentation process:

x_p (fraction of quark momentum carried by the hadron)

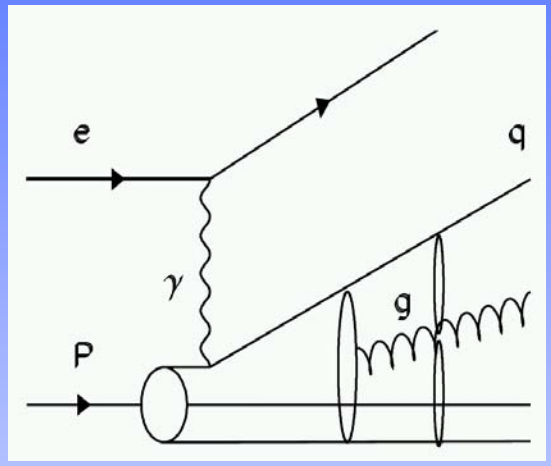
μ (energy scale of the quark)

$$\sigma^h = \text{PDF} \otimes \text{M.E.} \otimes \text{FF}$$

Models for ep scattering

ARIADNE

Color dipol model (CDM)



+

String fragmentation

HERWIG

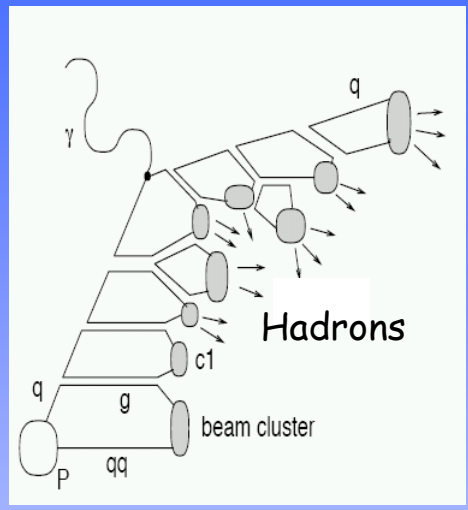
LO ME

+

Parton showers

+

Cluster fragmentation



RAPGAP/PYTHIA
DJANGOH,LEPTO

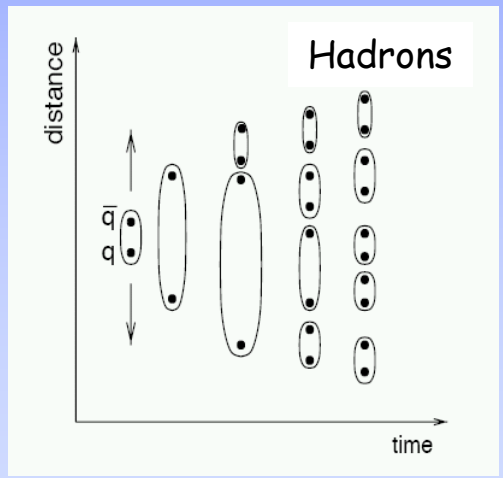
LO ME

+

Parton showers

+

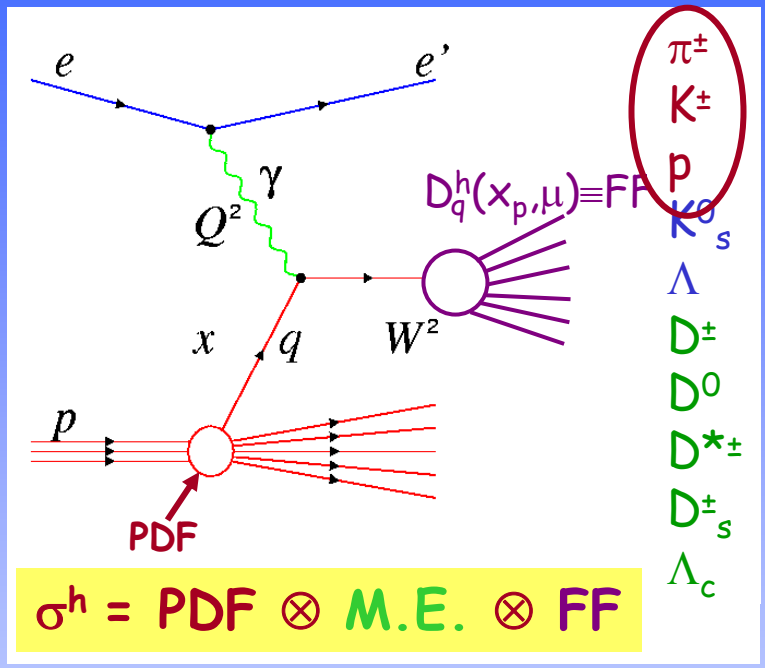
String fragmentation



(Fragmentation parameters tuned to e^+e^-)

Data sensitive to model differences?

Charged particle fragmentation function



H1 preliminary

Inclusive fragmentation function:
No distinction between $\pi^\pm$, $K^\pm$, p

Restricted to $100<Q^2<10000$ GeV^2

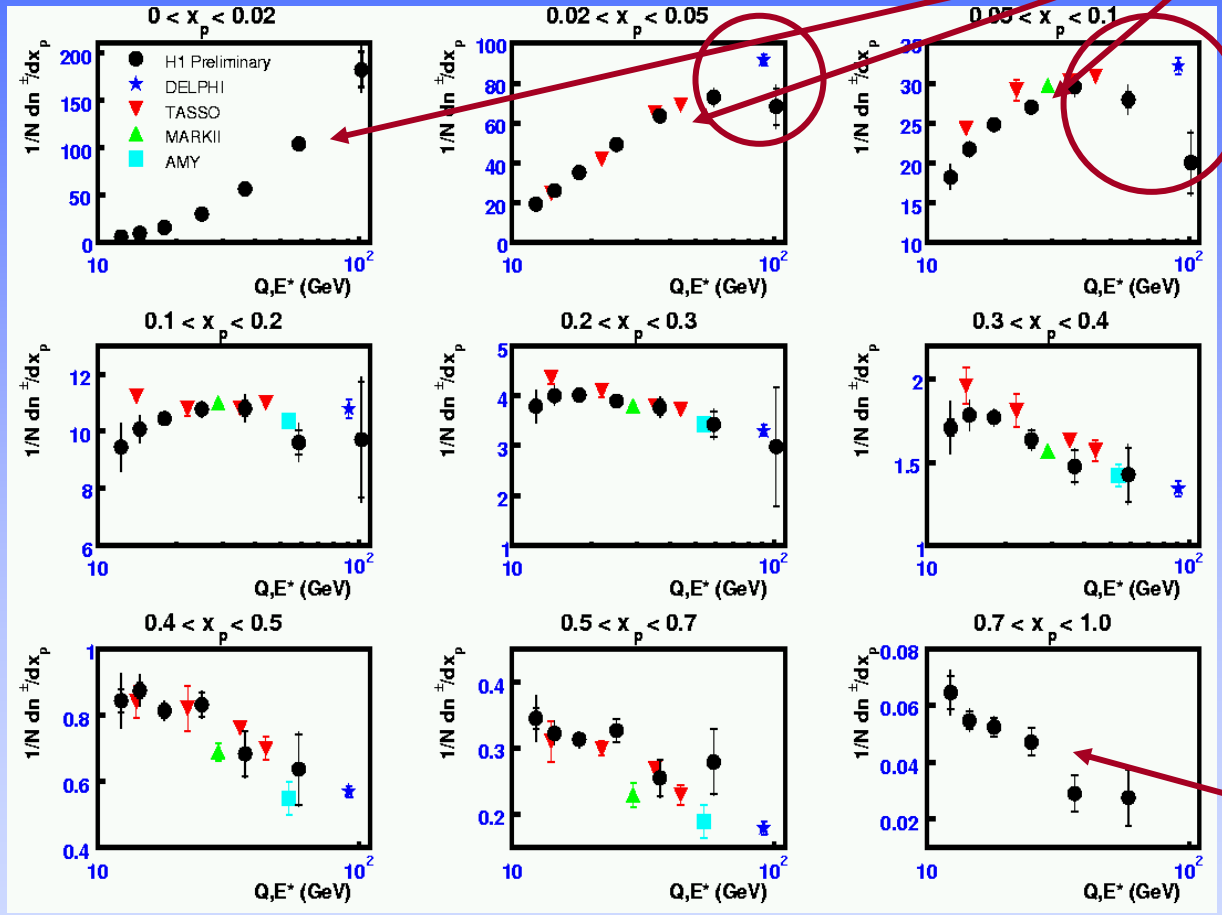
⇒Suppresses HO QCD effects not present in e^+e^- (e.g. boson-gluon-fusion, ISR)

Use a reference frame closest to situation in e+e-: (Breit-Frame)

⇒Energy scales:
ep-collisions: $\mu=Q/2$
e^+e^--annihilation: $\mu=\sqrt{s}/2=E_{beam}$

Charged particle fragmentation function

- **H1 preliminary (DIS)**



Steep rise with Q at small x_p Population due to gluon splitting P_{qg}

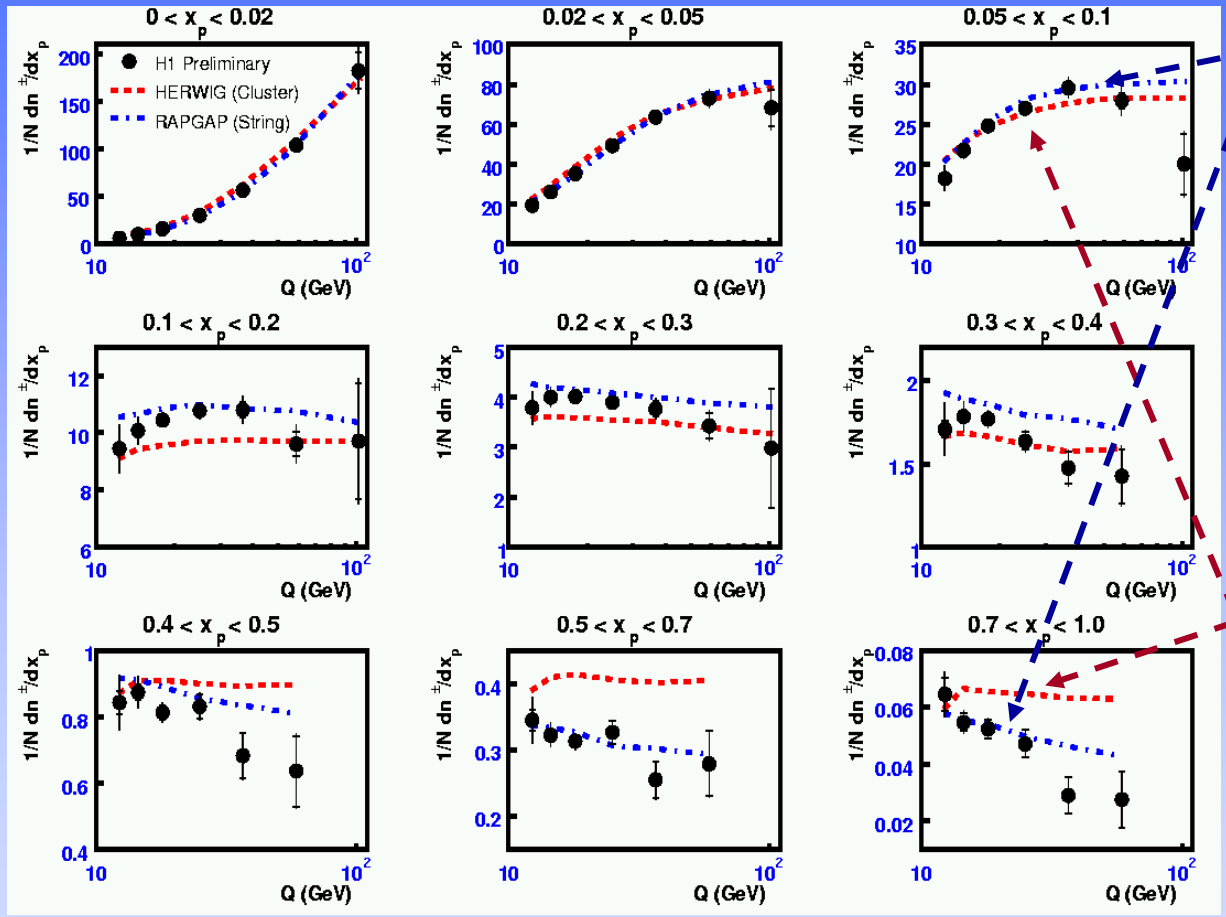
Overall agreement with e+e- data except at Large Q + small x_p

Steep fall with Q at large x_p Depletion due to gluon radiation P_{qq}

$\mu(ep)=Q/2$, $\mu(e^+e^-)=\sqrt{s}/2$

Charged particle fragmentation function

- **H1 preliminary (DIS)**

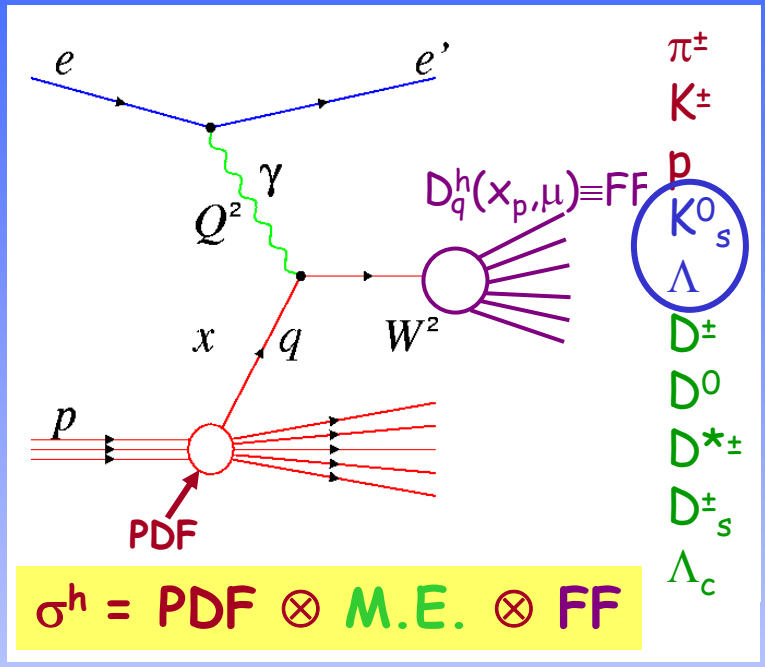


RAPGAP (string) describes the data in the full x_p,Q-range

HERWIG (cluster) describes the data at low x_p but fails at large x_p
(as if scaling violating contributions would be missing)

μ(ep)=Q/2

Strange particle production



ZEUS preliminary

Different regimes is ep-kinematic:

1. **DIS: Q^2>25 GeV²**
2. **DIS: 5<Q^2<25 GeV²**
3. **γp: Q^2≈0, 2 jets, E_T^{jet}> 5 GeV**

γ acts as a quasi-real target
⇒ may get internal structure (resolves into partons)

Distinction of direct γ from resolved γ via observable x_γ calculated from the two jets:

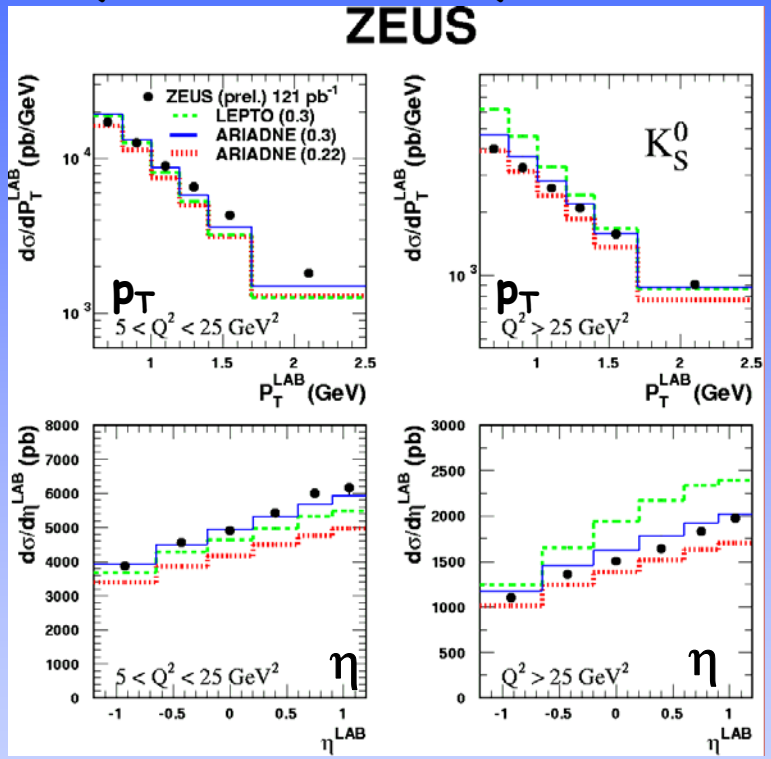
x_γ≈1 ⇒ direct γ
x_γ≪1 ⇒ resolved γ

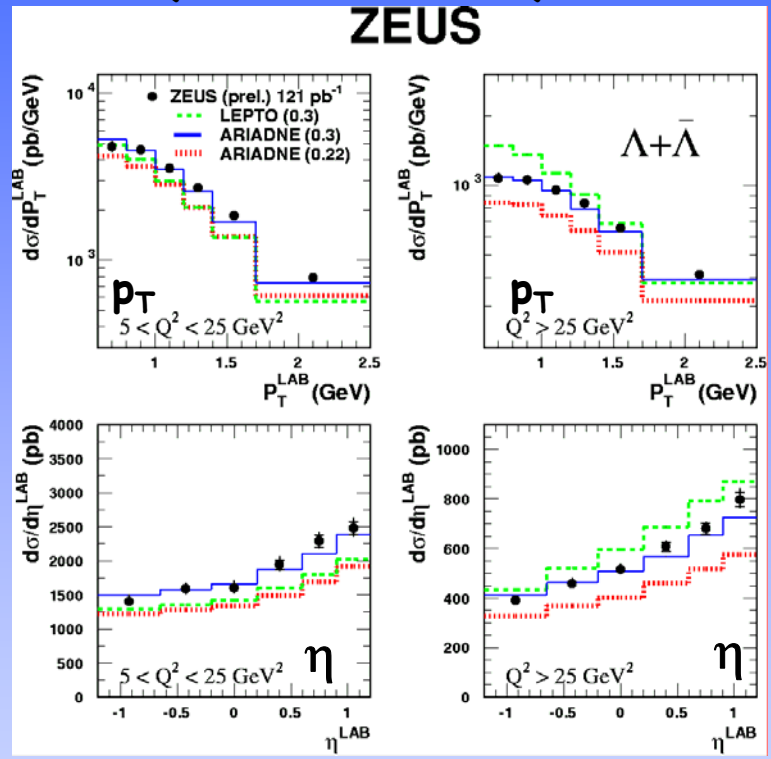
Due to the s-quark mass m_s fragmentation into K^0_s, Λ is suppressed w.r.t. π, p

⇒Strangeness suppression factor γ_s

Strange particle production

$5<Q^2<25\ GeV^2$ $Q^2>25\ GeV^2$ DIS $5<Q^2<25\ GeV^2$ $Q^2>25\ GeV^2$

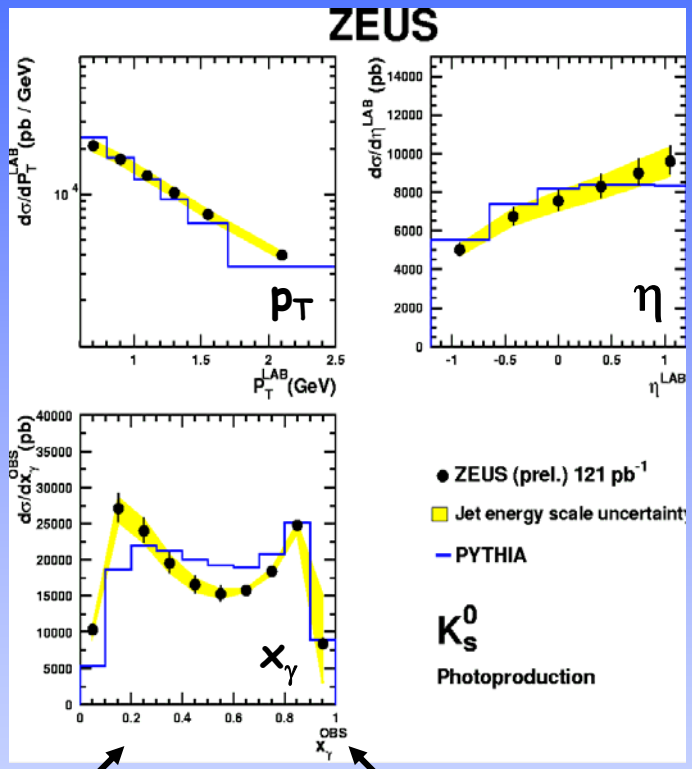


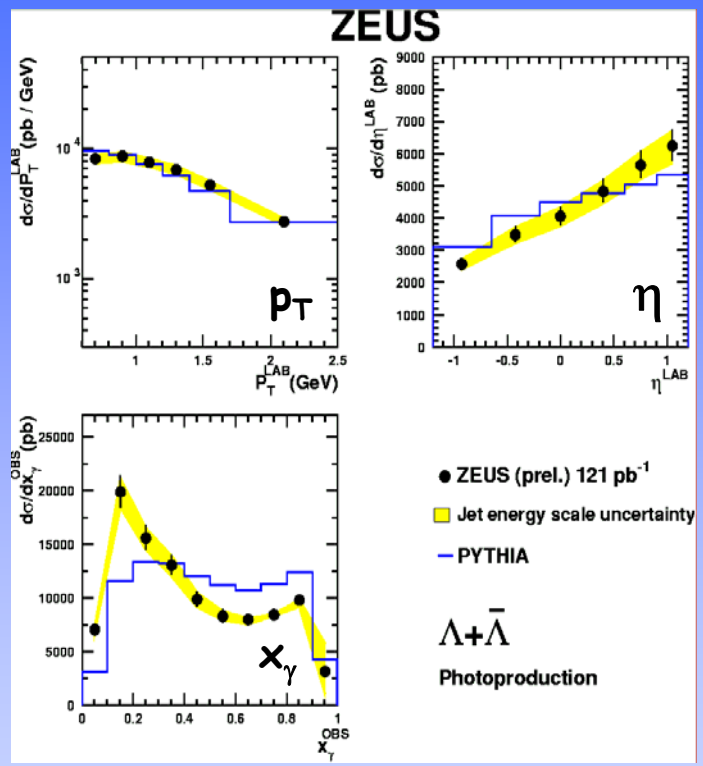


- ✔ ARIADNE γ_s=0.3 (CDM) overall reasonable – but shapes not so good
- ✘ ARIADNE γ_s=0.22 systematically too small (from previous result)
- ✘ LEPTO γ_s=0.3 (PS) fails
- ⇒ a single parameter γ_s possibly not sufficient to describe the data

Strange particle production

γp



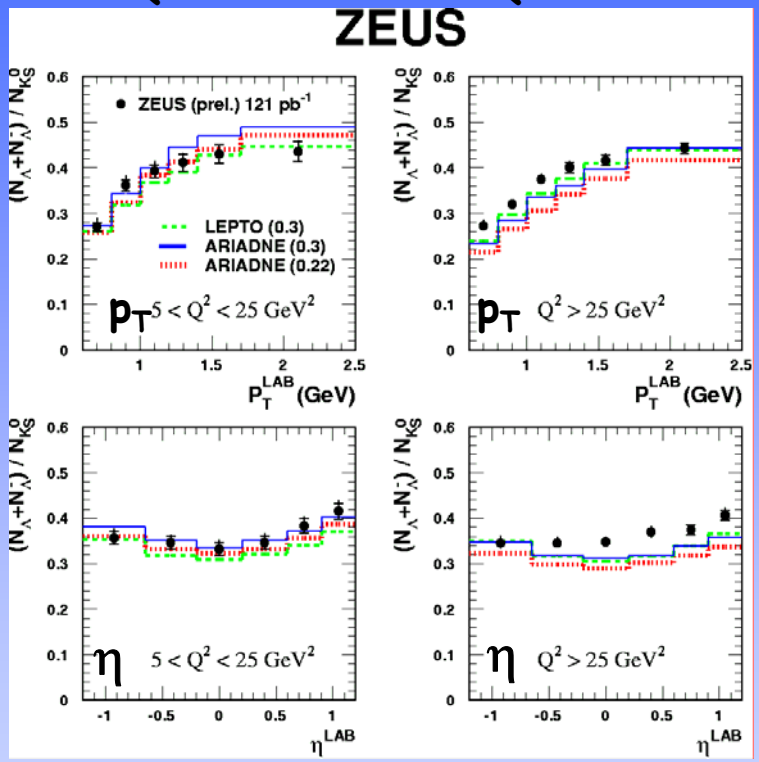


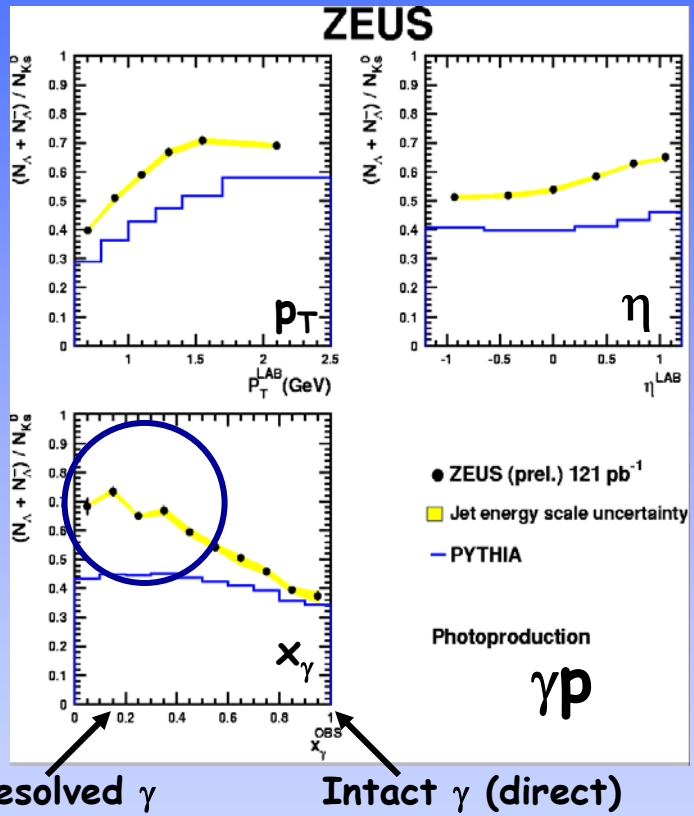
Resolved γ Intact γ (direct)

✔ PYTHIA reasonable in pt and η
✘ PYTHIA off in shape of x_γ (small x_γ)

Strange baryon-to-meson ratio

DIS $5<Q^2<25$ GeV^2 $Q^2>25$ GeV^2

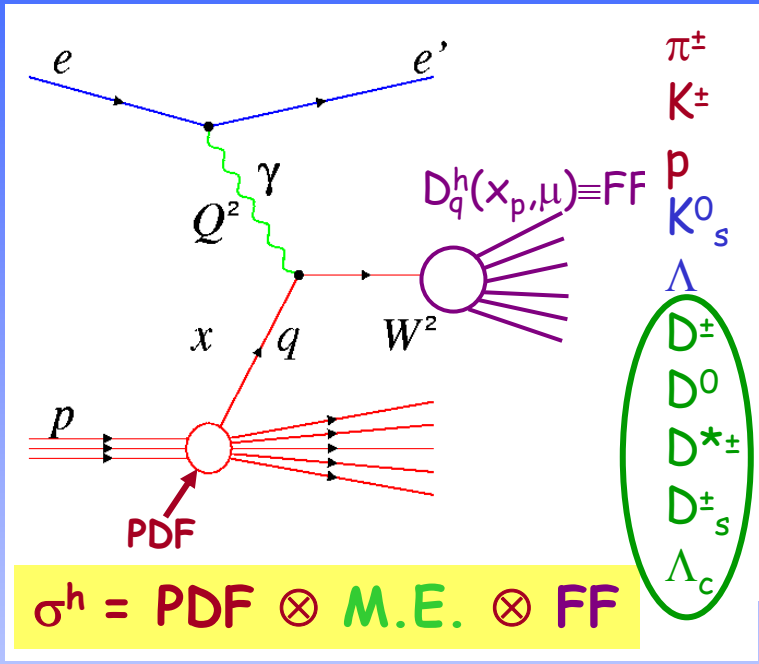




Resolved γ Intact γ (direct)

- ✔ ARIADNE (DIS) γ_s=0.3 quite good (10%)
- ✘ PYTHIA (γp) off in all distributions - especially @ small x_γ
- ✔ for x_γ=1 same baryon-to-meson ratio as in DIS and e^+e^-

Charm fragmentation fractions & function



Fragmentation fractions:

H1 (DIS) $2<Q^2<100$ GeV^2
using silicon vertex detector

ZEUS (γp)

ZEUS (DIS) $1.5<Q^2<1000$ GeV^2
preliminary

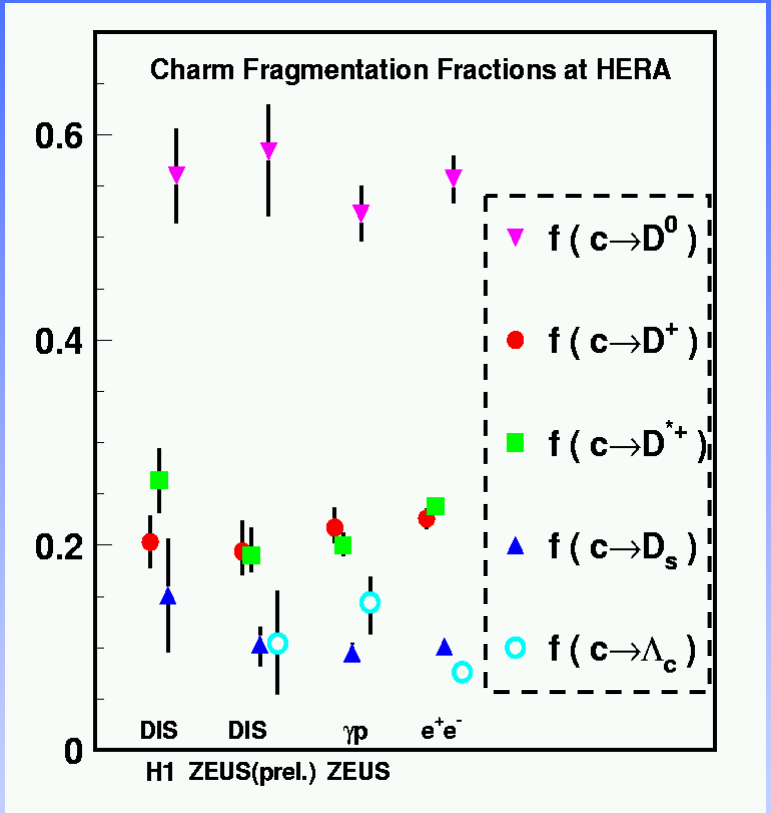
D* fragmentation function:

H1 (DIS) $2<Q^2<100$ GeV^2
preliminary

ZEUS (γp) $E_T^{jet}>9$ GeV
preliminary

Caveat:
Different definitions of fragmentation variable are used also in e^+e^-

Charm fragmentation fractions



Within experimental precision:
Charm fragmentation fractions independent of hard subprocess
⇒ consistent with universality of charm fragmentation fractions

Charm fragmentation ratios from D's

Isospin invariance:

$$R_{u/d} = \frac{c\bar{u}}{c\bar{d}} \quad *)$$

expected to be 1

Strangeness suppression:

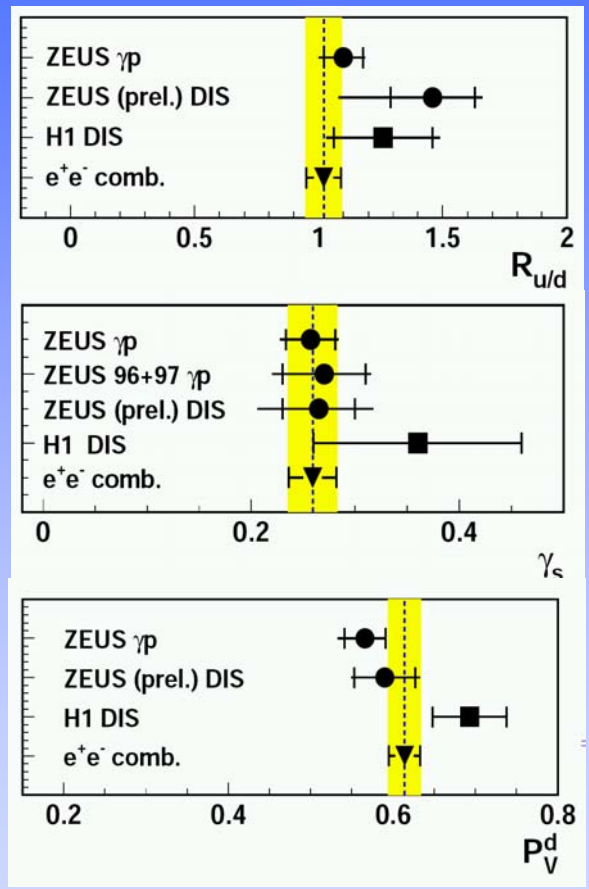
$$\gamma_s = \frac{2c\bar{s}}{c\bar{u} + c\bar{d}} \quad *)$$

Fraction of vectormesons:

$$P_V^d = \frac{V(c\bar{d})}{P(c\bar{d}) + V(c\bar{d})} \quad *)$$

Naïve spin counting :3/4

*) charge conjugate always implied



Within errors:

Consistent with 1 for all processes

Suppressed by ≈4

Consistent with light flavours?

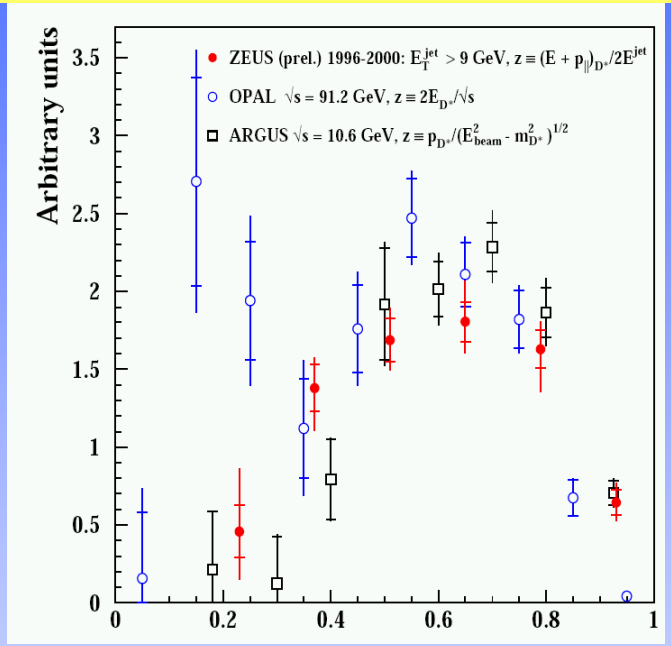
$P_v \neq 3/4$

Naïve spin counting does not work!

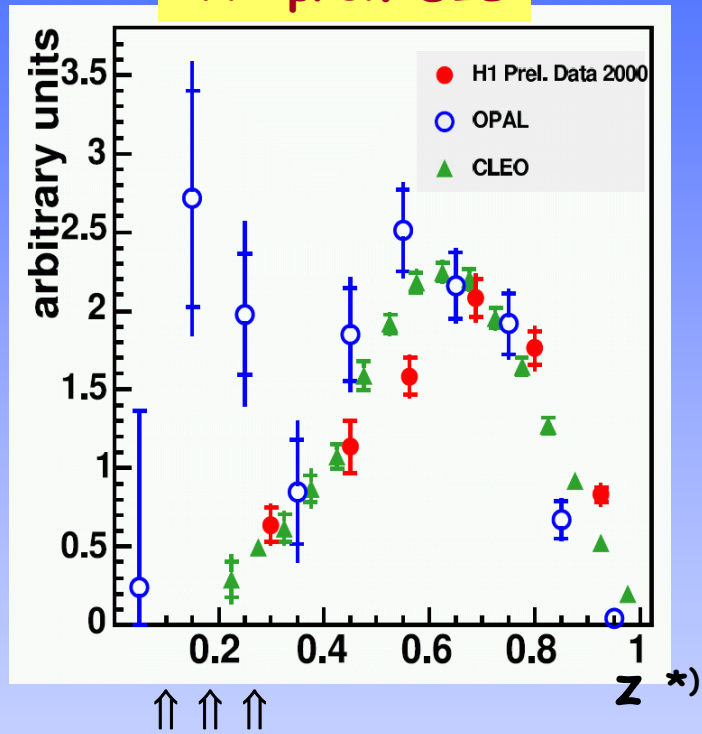
Consistency between all processes

D* fragmentation function in ep and e^+e^-

•ZEUS prel. γp, $E_T^{jet} > 9$ GeV



•H1 prel. DIS

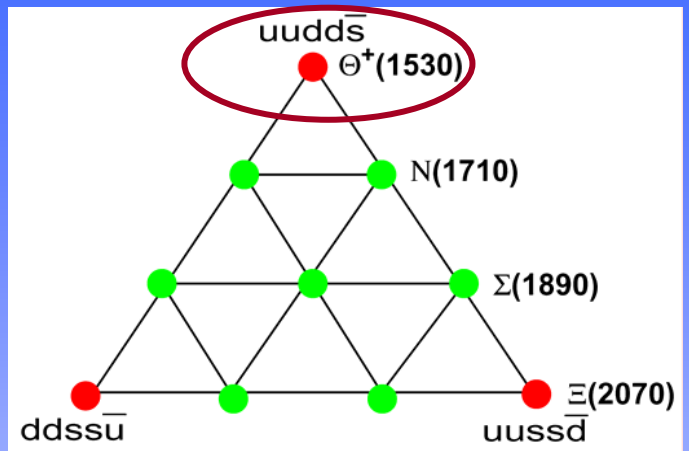


No contributions from gluon splitting at low energies

Qualitative agreement

*) different definitions of z

Search for exotic baryons - $\Theta^+(1540)$



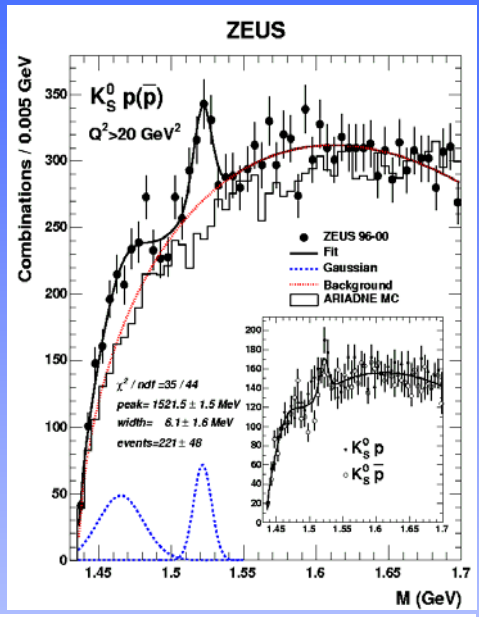
Searches at HERA: $\Theta^+ \to K^0_s\, p$

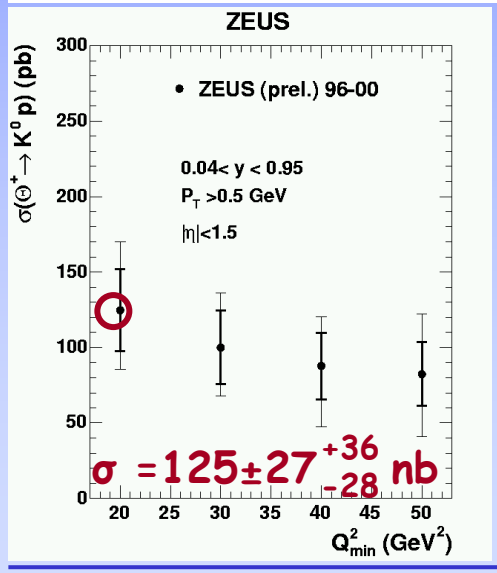
ZEUS:

DIS, $Q^2 > 20$ GeV^2

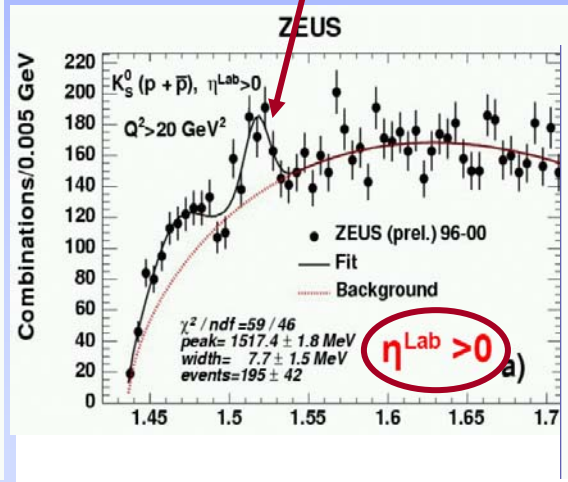
221 events
$M(\Theta^+) = 1522$ MeV
$\sigma = 6$ MeV

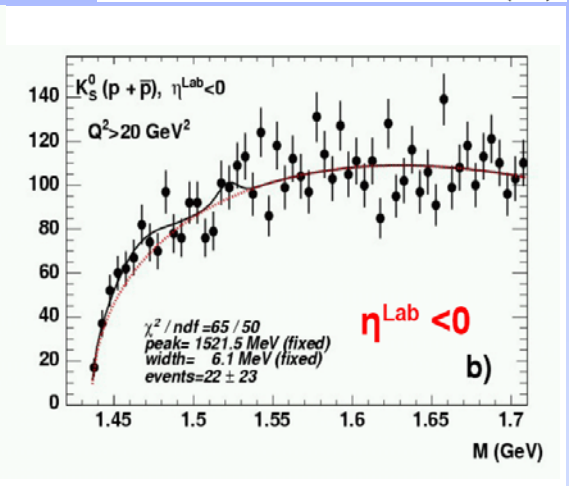
Significance: 4.6σ





Mainly towards proton direction



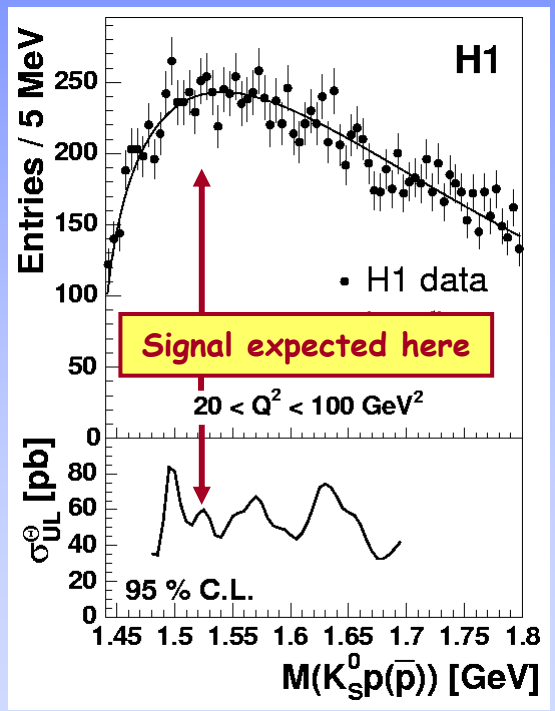


Search for exotic baryons – $\Theta^+(1540)$

H1:

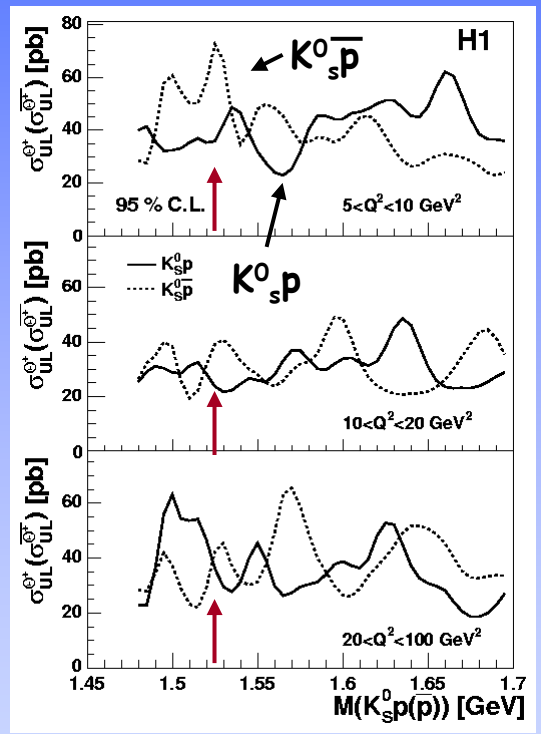
DIS, bins in Q^2

No signal found
$\Rightarrow$ $M(K^0_S p)$ dependent limits @ 95% C.L.



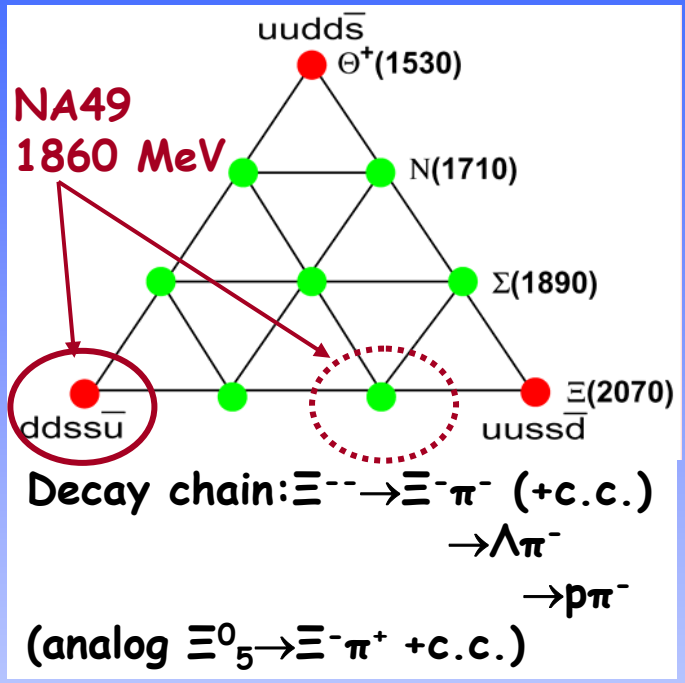
Consistent with fluctuations only

Limits in bins of Q^2 for $K^0_S p$ and $K^0_S \bar{p}$ separately



Limit for similar to selection of ZEUS:
$\sigma(M=1.52) < 72$pb @ 95% C.L.

Search for exotic baryons - Ξ^{--}



Decay chain: $\Xi^{--} \rightarrow \Xi^{-}\pi^{-}$ (+c.c.)

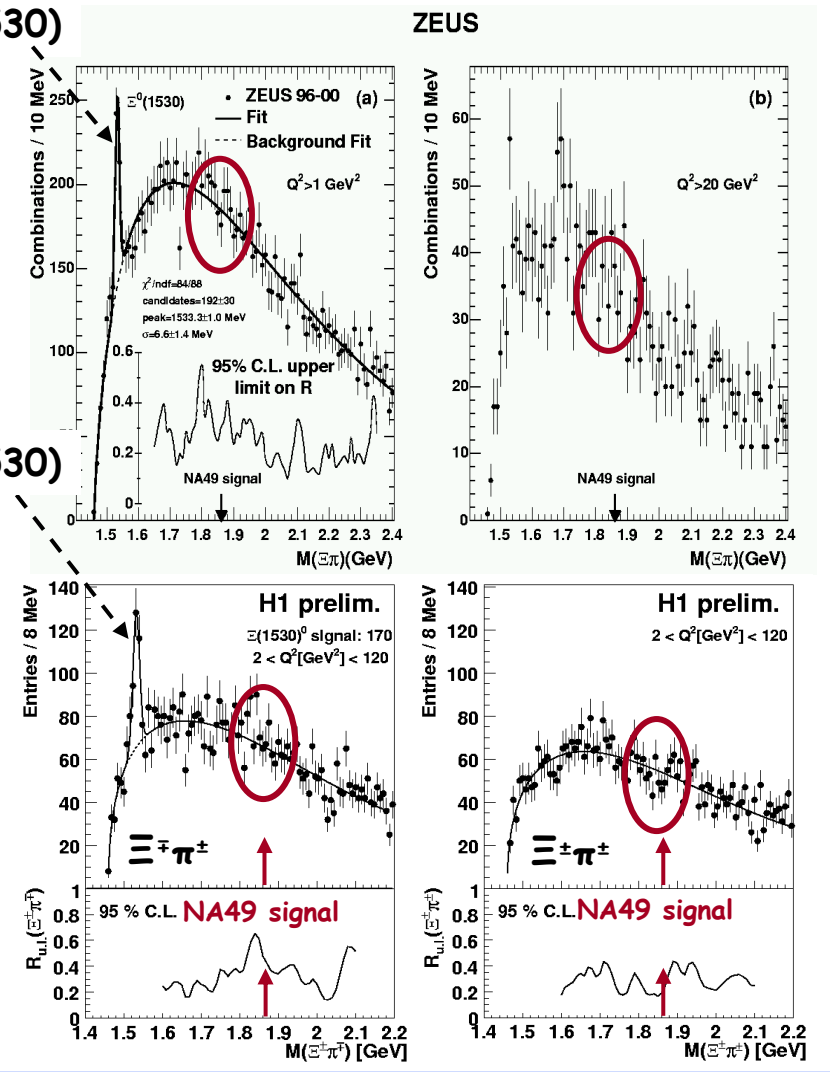
$\rightarrow \Lambda\pi^{-}$

$\rightarrow p\pi^{-}$

(analog $\Xi^{0}_{5} \rightarrow \Xi^{-}\pi^{+}$ +c.c.)

$\Xi^{0*}(1530)$

$\Xi^{0*}(1530)$



ZEUS: DIS, $Q^2 > 1$ GeV^2

H1 prel.: DIS, $2 < Q^2 < 100$ GeV^2

No signals ⇒ Upper limits @95% C.L.

$R(\Xi^{--}(1860)/\Xi^{0*}(1530))$

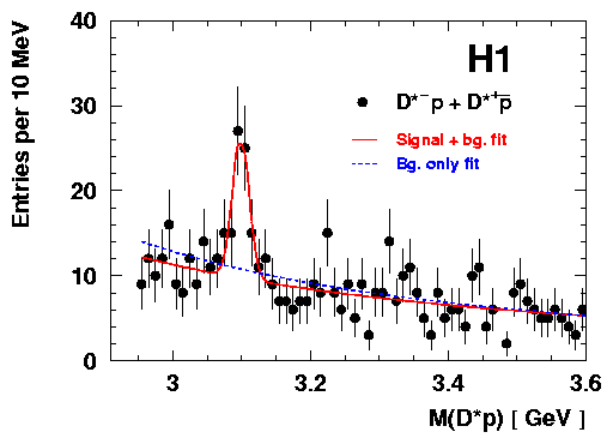
< 0.29 ZEUS

< 0.20 H1

Search for exotic charmed baryon

A possible charmed analogue of Θ^+ could decay to $D^{*-}p$ (+c.c.)

H1: DIS $1<Q^2<100$ GeV^2
Signal of 51 events observed
@ M(D*p)=3099 MeV

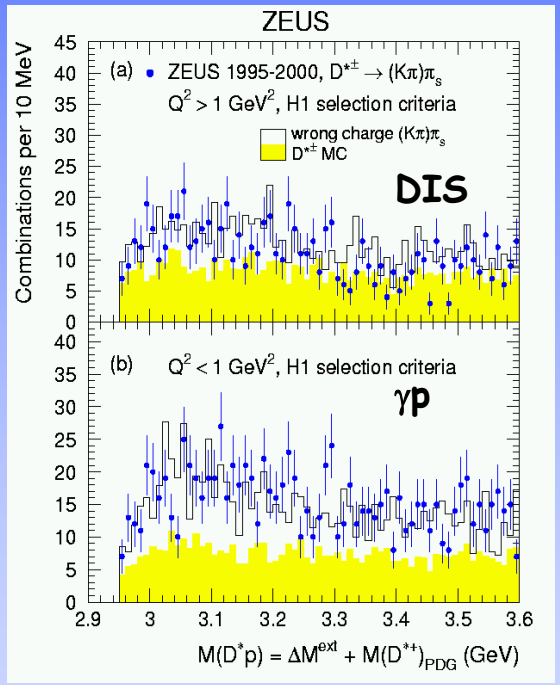


Background fluctuation probability:
$4*10^{-8}$ (Poisson) $\rightarrow$ 5.4σ (Gauss)
Signal also present in γp

Acceptance corrected ratio:

$R_{cor}(D^*p/D^*) = 1.59 \pm 0.33\,^{+0.33}_{-0.45}$ %

ZEUS: DIS $Q^2>1$ GeV^2 and γp
No signals observed



Acceptance corrected upper limit:

$R^{cor}(D^*p/D^*) < 0.59\%$ @95% C.L. (DIS)

Conclusions

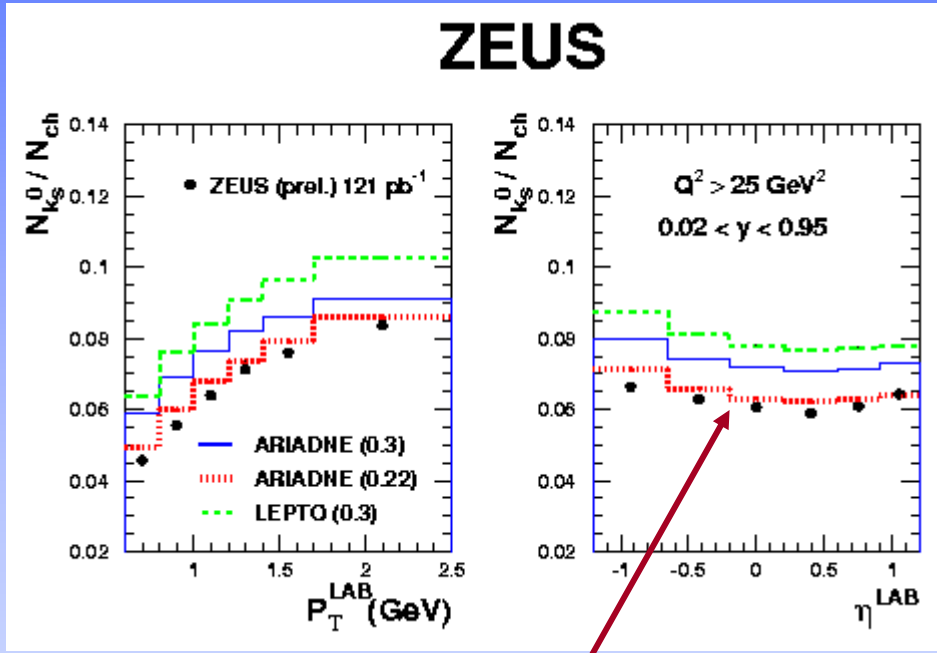
- Charged particle fragmentation function in ep collisions
  - shows significant scaling violations
  - agrees generally with e^+e^- annihilation data
  - cluster model fails to describe scaling violations
- Strange particle production in ep collisions
  - is reasonably described in DIS with γ_s=0.3 (LEP tuning)
  - model fails to describe $(\Lambda+\bar{\Lambda})/K^0_s$ ratio in resolved γp
  - consistent $(\Lambda+\bar{\Lambda})/K^0_s$ ratios in DIS, direct γp and e^+e^-
- Charmed particle production
  - fragmentation fractions, ratios & function are process independent (consistent with universality)
- Searches for exotic baryons in ep collisions:
  - the situation is mixed – final HERA statistic needed (x4)

Sunset at Agua de Pau

Backup Slides

Ratio of $K^0_s/(\pi^{\pm}+K^{\pm}+p+\bar{p})$

K^0_s and Λ production cross sections in DIS are best described by ARIADNE using γ_s=0.3 (LEP-tuning)
However:



ratio $K^0_s/(\pi^{\pm}+K^{\pm}+p+\bar{p})$ prefers $\gamma s \leq 0.22$

Possible explanation of excess at x_γ<<1

Fireball:

⇒ isotropic energy distribution
⇒ $E_T^{jets} << \Sigma|E_T|$

⇒ select fireball enriched sample:
$E_T^{jets}/\Sigma|E_T| < 0.3$

fireball depleted sample:
$E_T^{jets}/\Sigma|E_T| > 0.3$

⇒ fireball depleted sample:
model expectation closer to data