Particle production and spectroscopy at HERA

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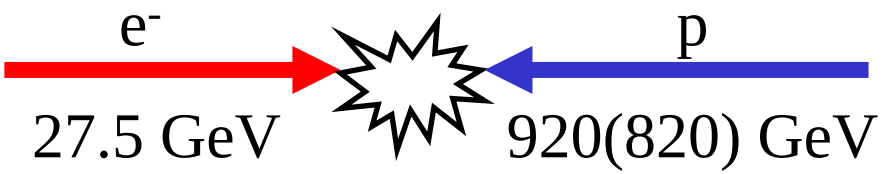
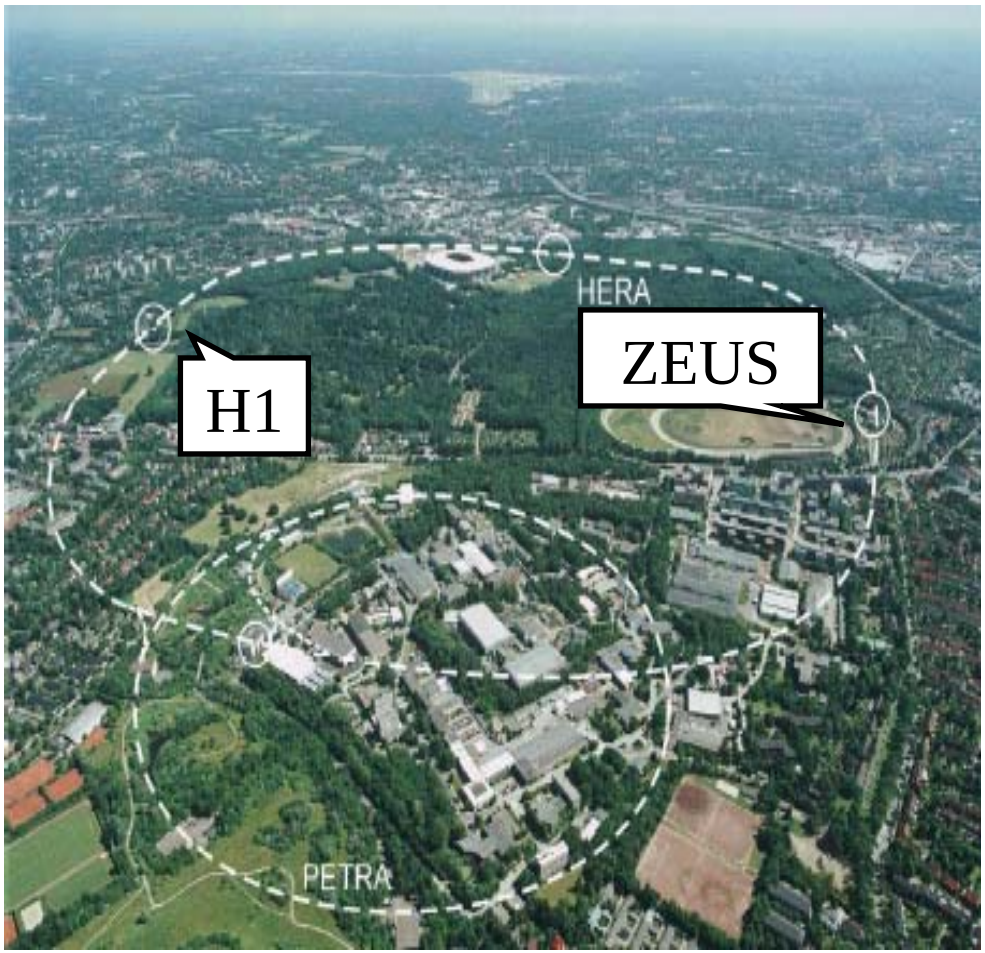
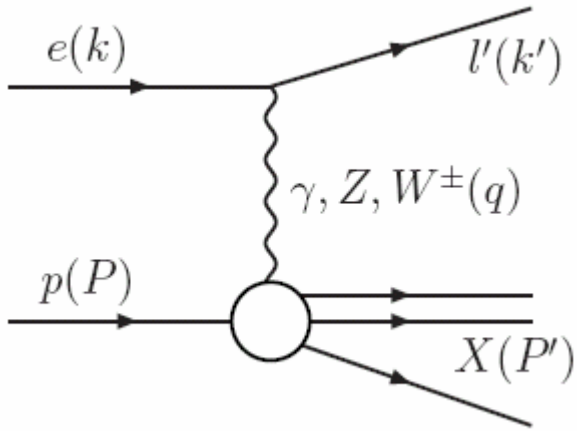
for the ZEUS and H1 collaborations

1. Motivation for particle production studies
2. Charged particle production
3. Strangeness production (K^0_s, Λ^0)
4. Pentaquarks searches (θ^+, θ_c)
5. Conclusions

The HERA Collider







Kinematical variables

$\sqrt{s}$=320(300) GeV ep CM energy

$Q^2=-q^2$ photon virtuality, squared four-momentum transfer

$x=Q^2/(2qP)$ Bjorken scaling variable

$y=Q^2/(xs)$ inelasticity

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

$Q^{2\sim}$ 1 GeV^2 : photoproduction

Motivation – what can we learn from particle production at HERA?

pQCD

Charged particle production

- Scaling violation

npQCD

Charged particle production

- String/Cluster fragmentation?

Strangeness production

- Strangeness suppression factor – parameter in string fragmentation model

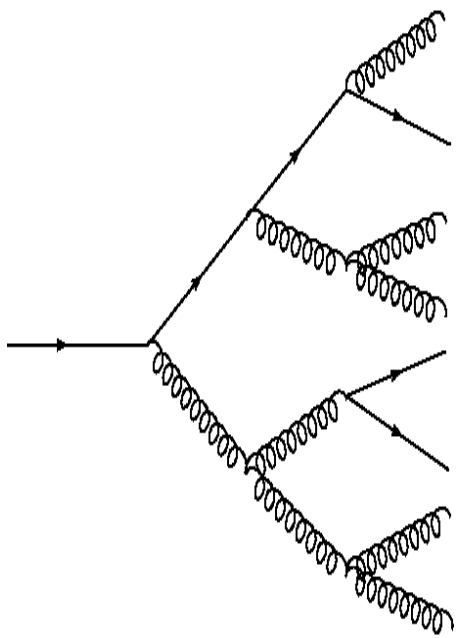
Pentaquarks production

- Fragmentation study

Quark Fragmentation

pQCD

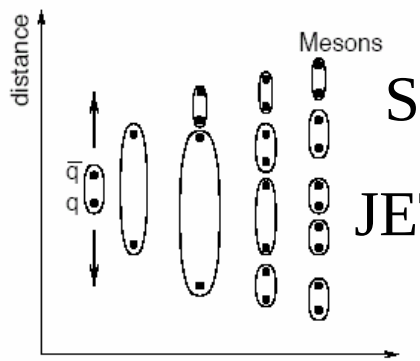
pert. calculable part



Hadronisation

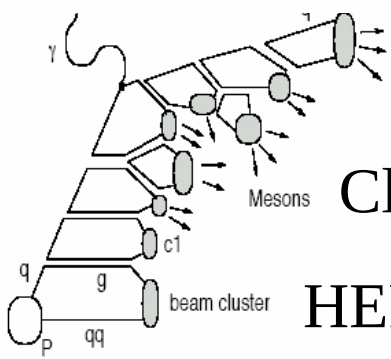
npQCD

measurable part



String

JETSET



Cluster

HERWIG

$\pi^{+/-}$

p

$K^{+/-}$

K^0

Λ^0

θ^+

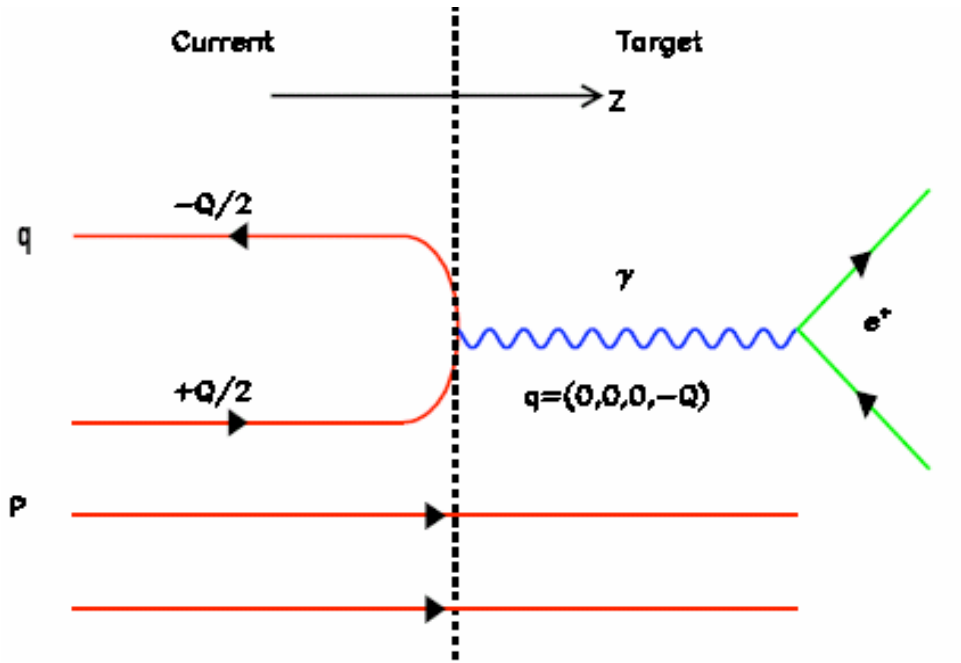
θ_c

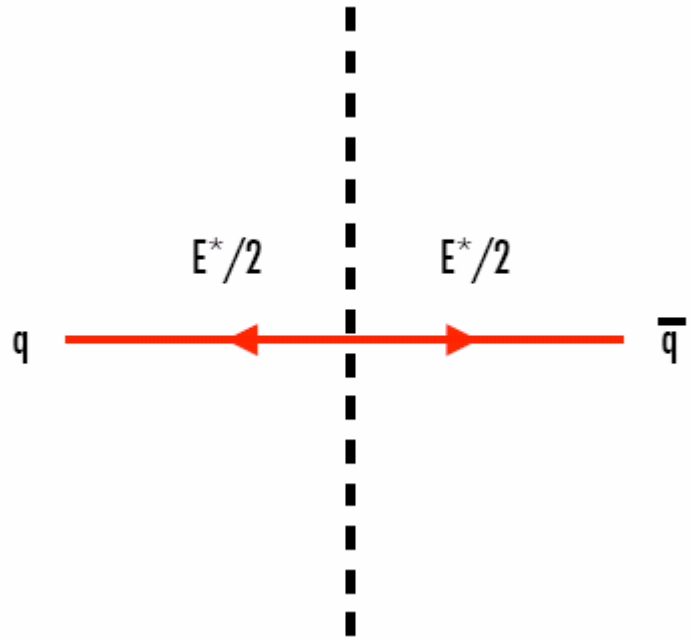
Charged particle at $Q^2>100\ GeV^2$

- Quark fragmentation universality
  (comparison with e^+e^-)
- Test of hadronisation (String, Cluster)
- Test of fragmentation (CDM, PS)

Charged particle at $Q^2>100$ GeV^2: e^+e^- vs ep

ep current region of Breit frame (struck quark) compare to hemisphere $e^+e^- \rightarrow qq$





$$x_p = \frac{(2P_h)}{Q}$$

p_h = momentum of charged track in the current region of Breit frame

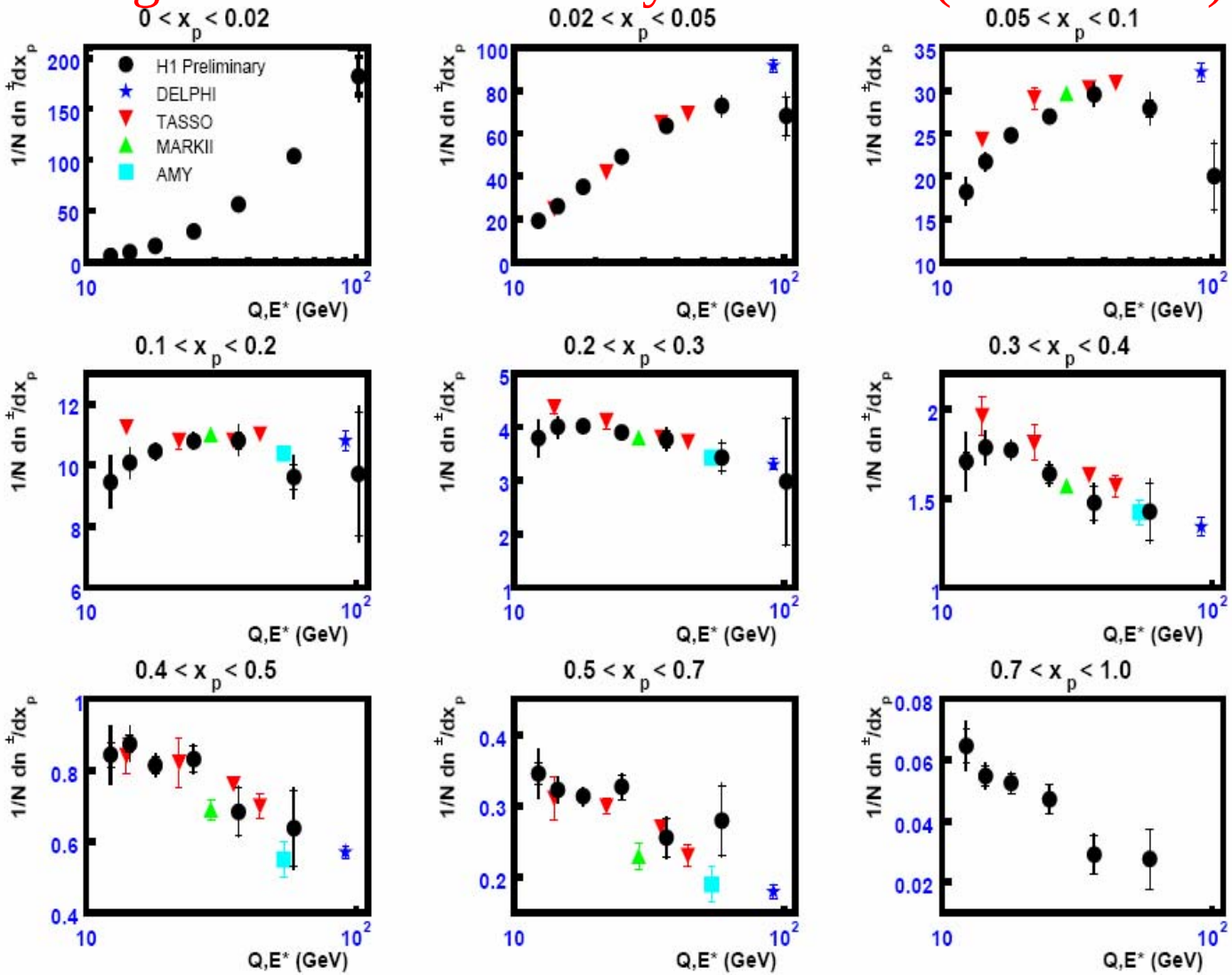
$$\frac{1}{N_{event}} dn/dx_p$$

= charged particle scaled momentum spectrum

Scale Q in DIS equivalent to E^* in e^+e^-

Charged particle at $Q^2>100$ GeV^2: fragmentation study

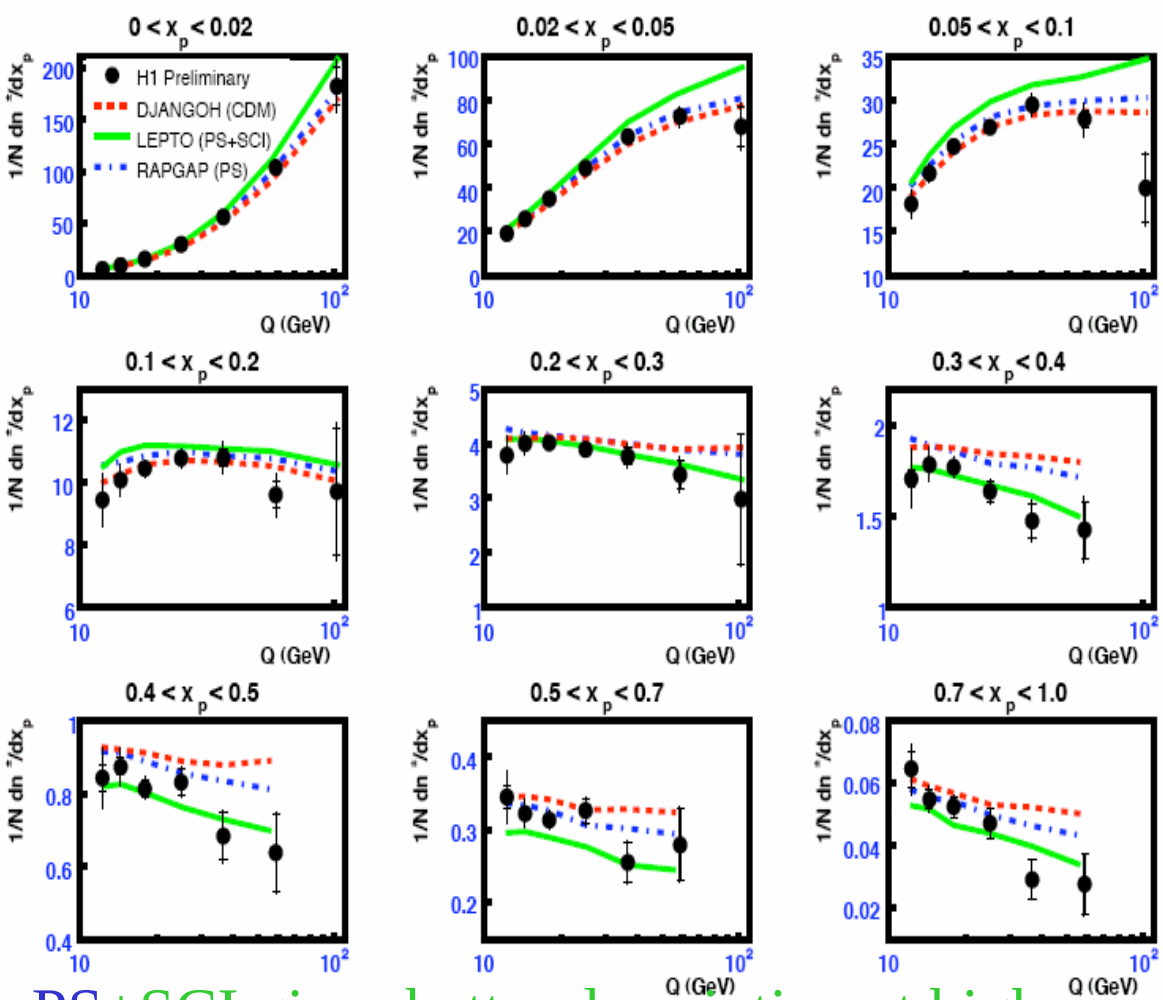
Fragmentation universality confirmed (e^+e^- vs DIS)



Discrepancy at low Q (E^*) due to Higher Orders processes

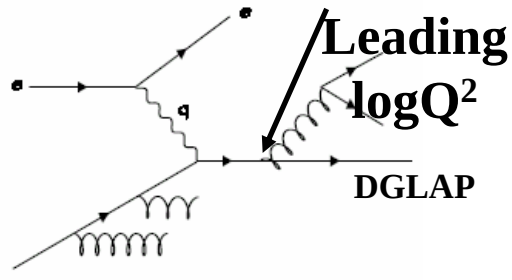
Charged particle at $Q^2>100$ GeV^2: fragmentation study

PS and CDM give similar description of the data

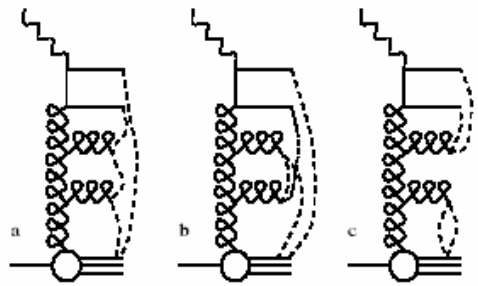


PS+SCI gives better description at high x_p

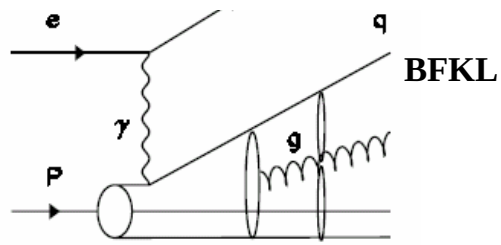
(Additonal gluon interactions in SCI)



Parton Shower (RAPGAP)



Soft Color Interactions (LEPTO)

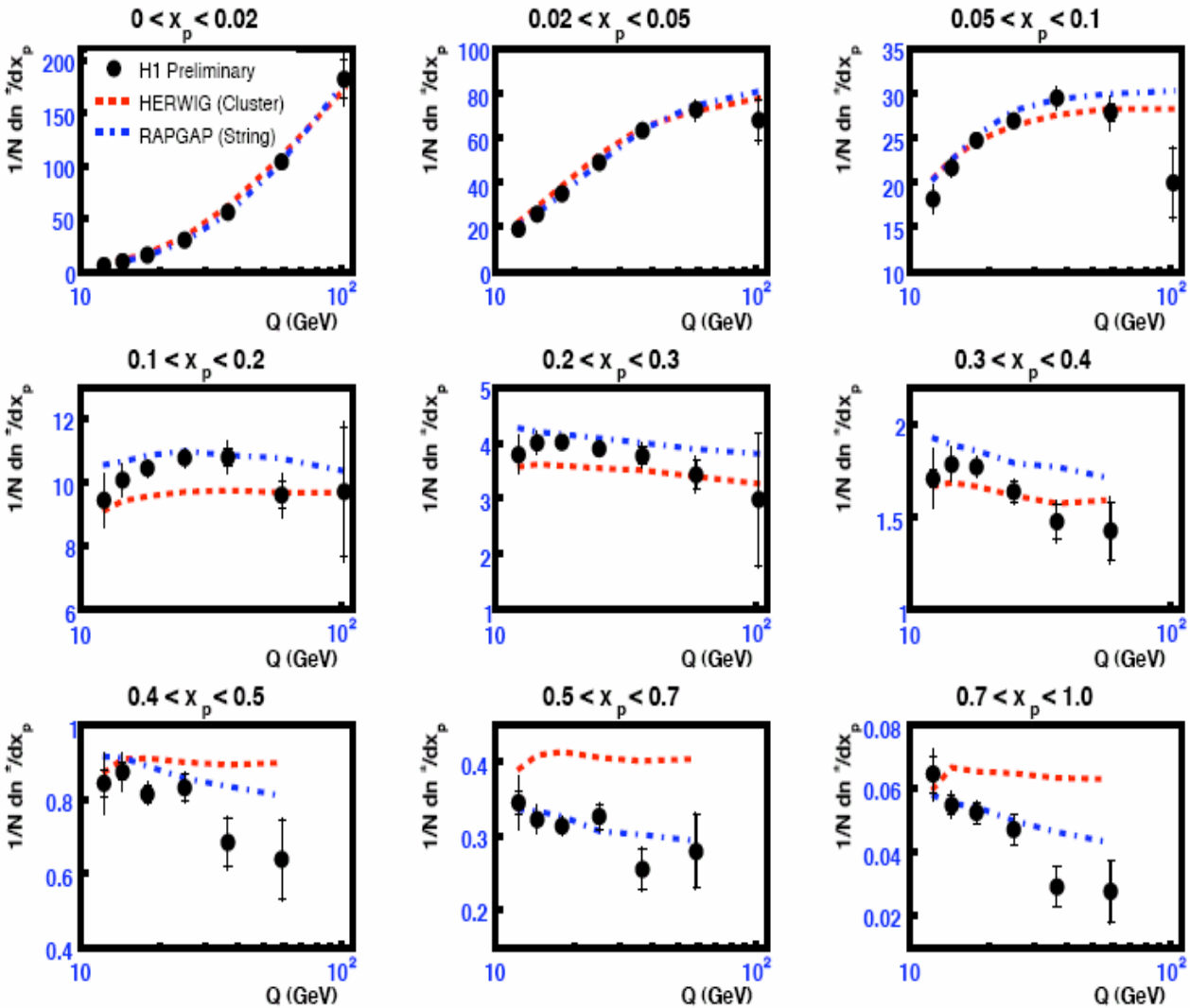


Color Dipol Model

(ARIADNE, DJANGO)

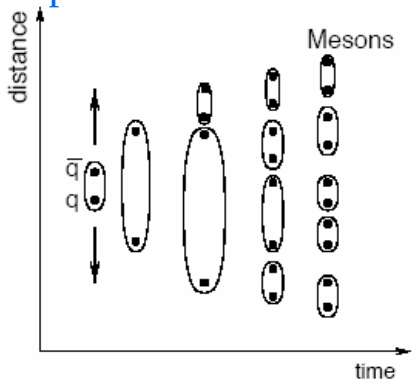
Charged particle at $Q^2>100$ GeV^2: hadronisation study

String fragmentation better than cluster fragmentation

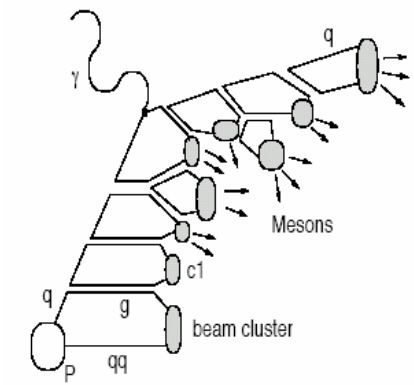


String fragmentation

Implemented in RAPGAP



Cluster fragmentation HERWIG



Neutral strange particles

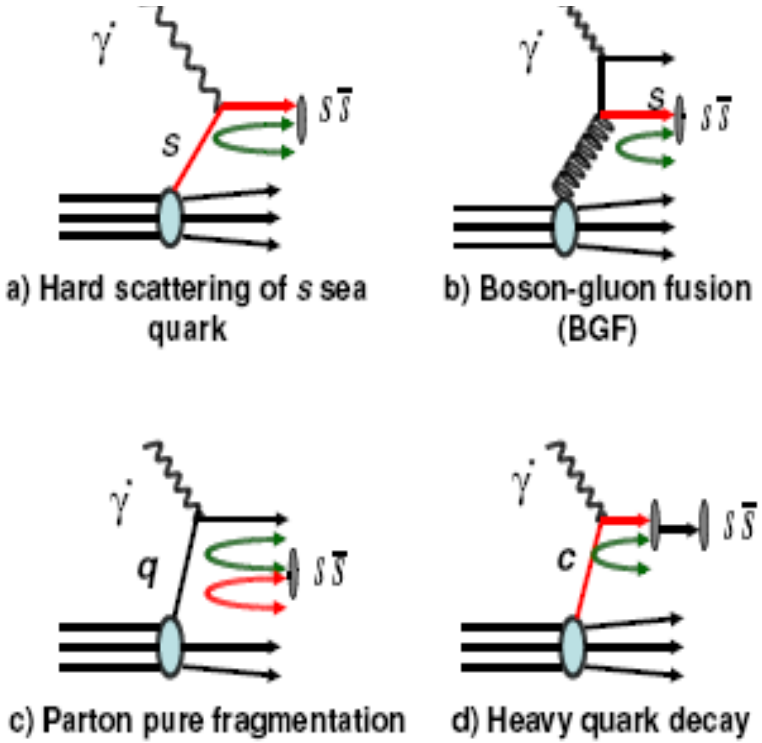
- Strangeness suppresion factor (λ_s) – parameter of Lund string model (sensitive to hadronisation)

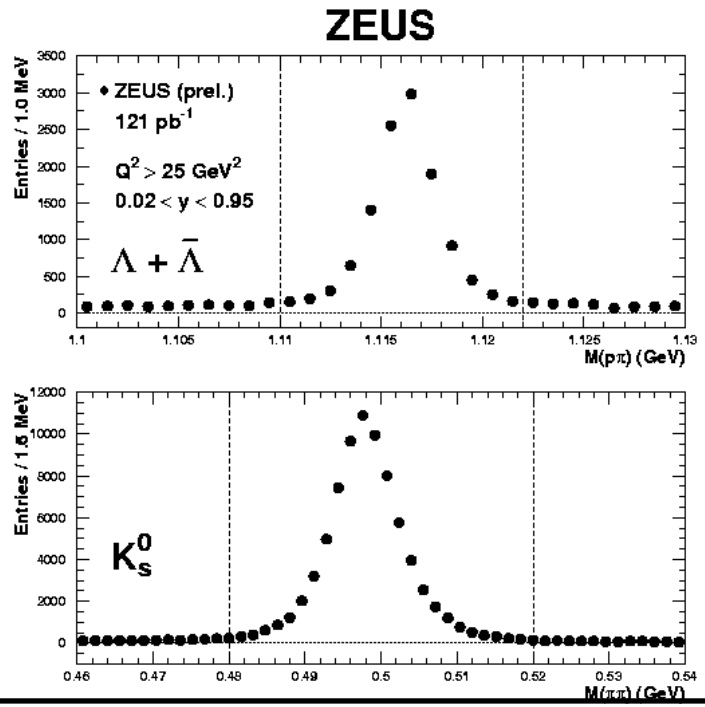
1. Inclusive cross sections
2. Ratio of strange to light hadrons

Strangeness production

Dominated by hadronisation?

$\lambda_s = P(s)/P(u)$





ZEUS 1996-2000 data 121 pb^{-1}

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

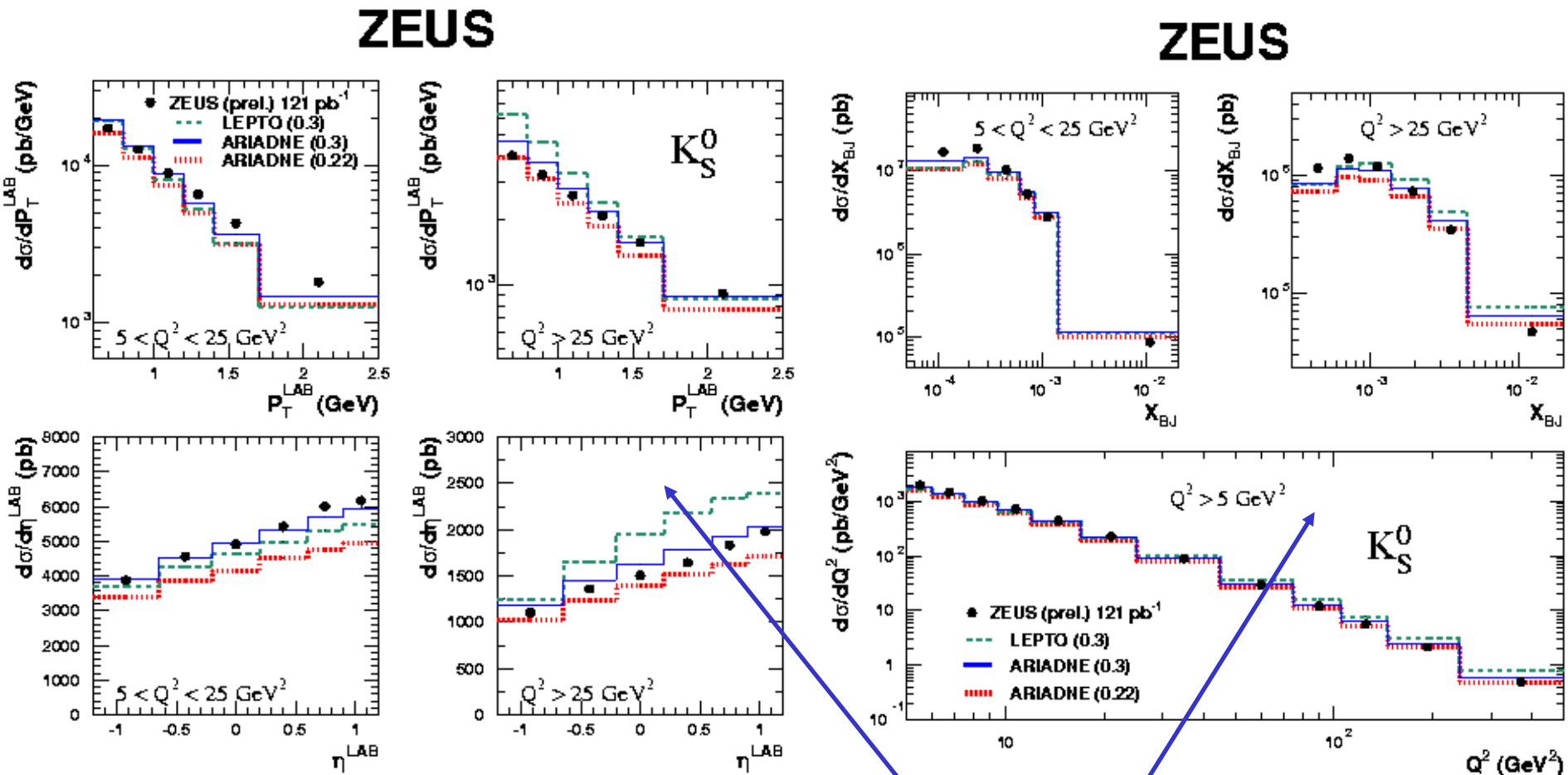
$0.02<y<0.95$

$0.6<p_t(K^0_s,\Lambda)<2.5$ GeV

$\eta\ |(K^0_s,\Lambda)|<1.2$

Strangeness production

Differential K^0_s cross section in LAB frame

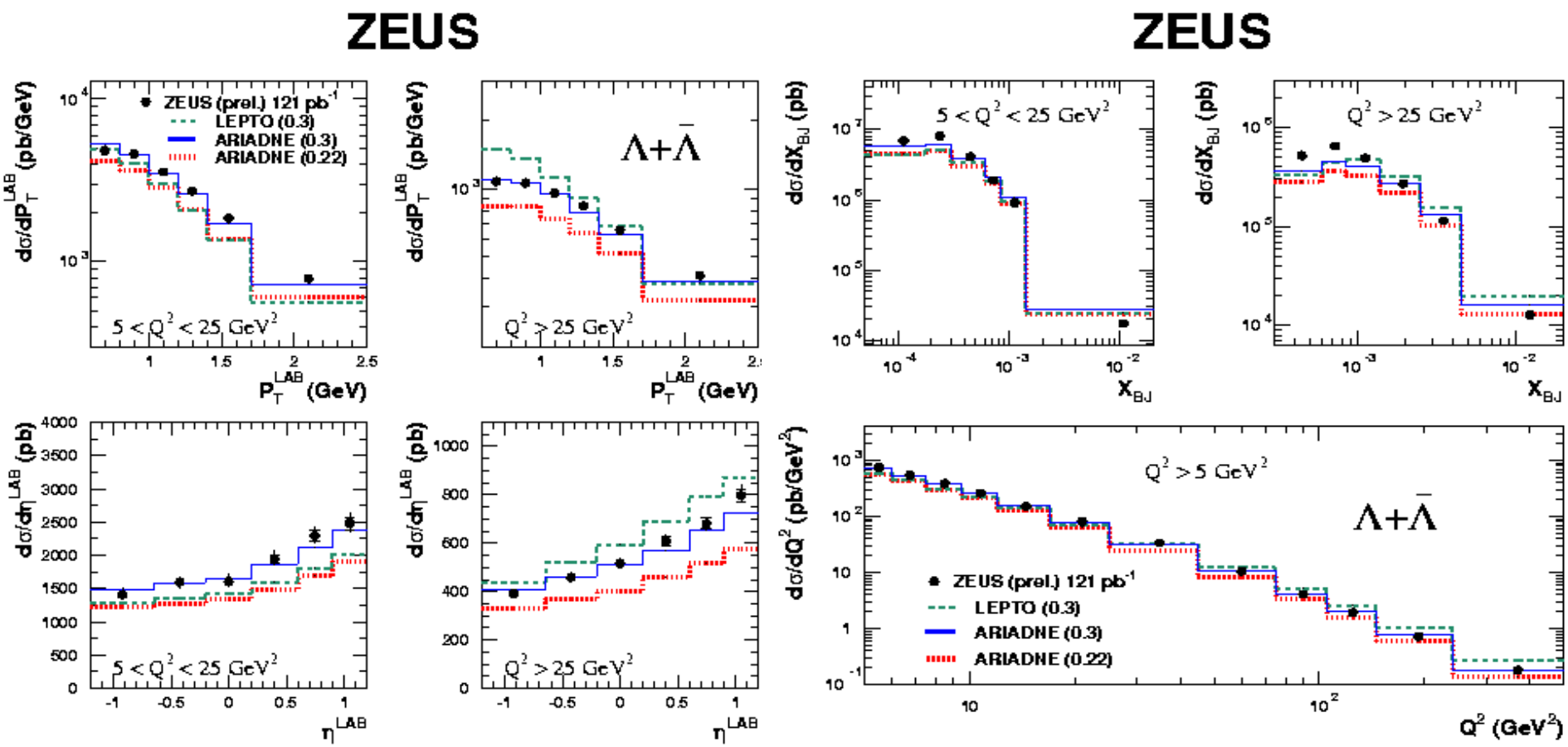


e^-e^+ (LEP tuning) : $\lambda_s = 0.3$

$\lambda_s = 0.3$ describes ep data well

Strangeness production

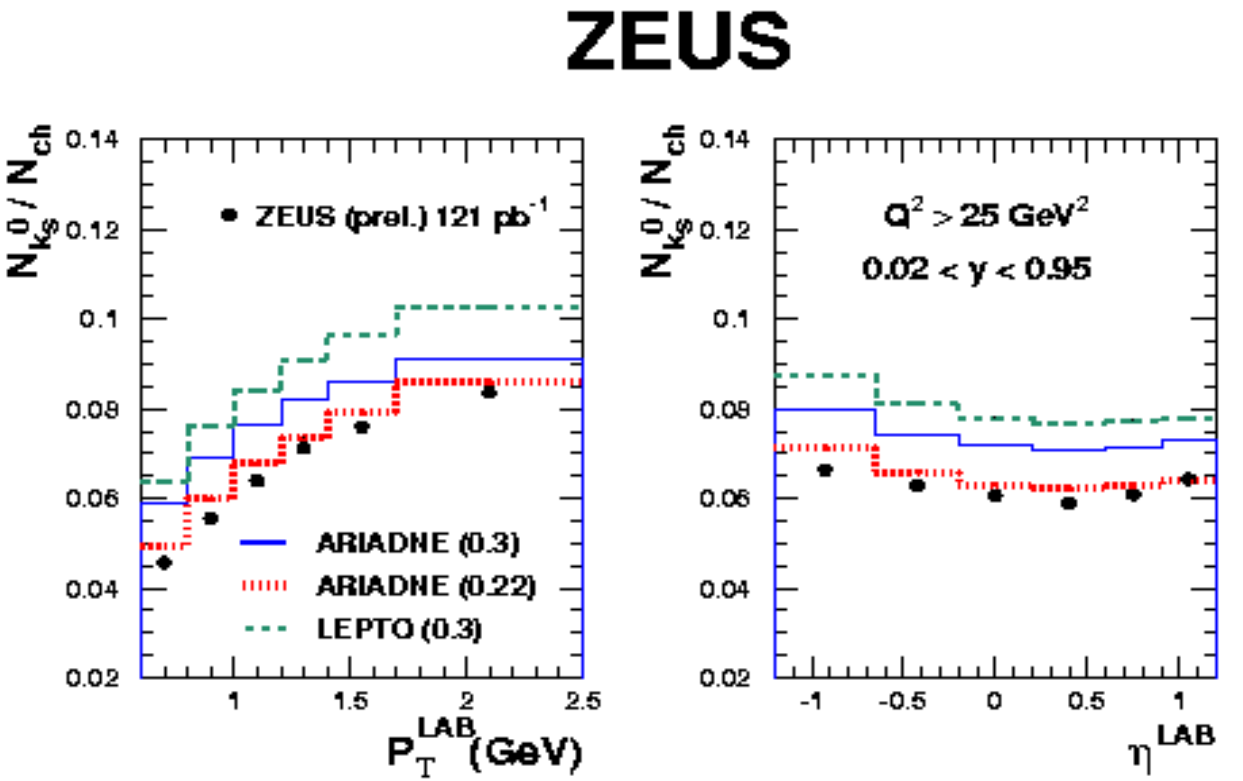
Differential Λ^0 cross section in LAB frame



$\lambda_s = 0.3$ describes data well

Strangeness production

λ_s universal? Different strangeness suppression for inclusive cross sections and ratio of strange to light hadrons!



N_{ch} – number of charged pions, charged kaons, protons and antiprotons

ARIADNE with λ_s= 0.22 describes data well

Pentaquarks

- $\theta^{+} \rightarrow K^{0}_{s} p$
- $\theta_{c} \rightarrow D^{*} p$

Strange pentaquark $\theta^+ \rightarrow K^0_s p$: ZEUS results

ZEUS 1996-2000 data 121pb^{-1}

DIS: $Q^2>20$ GeV; $0.04<y<0.95$

$\theta^+ \rightarrow K^0_s p$, $K^0_s \rightarrow \pi^+\pi$, p via dE/dx

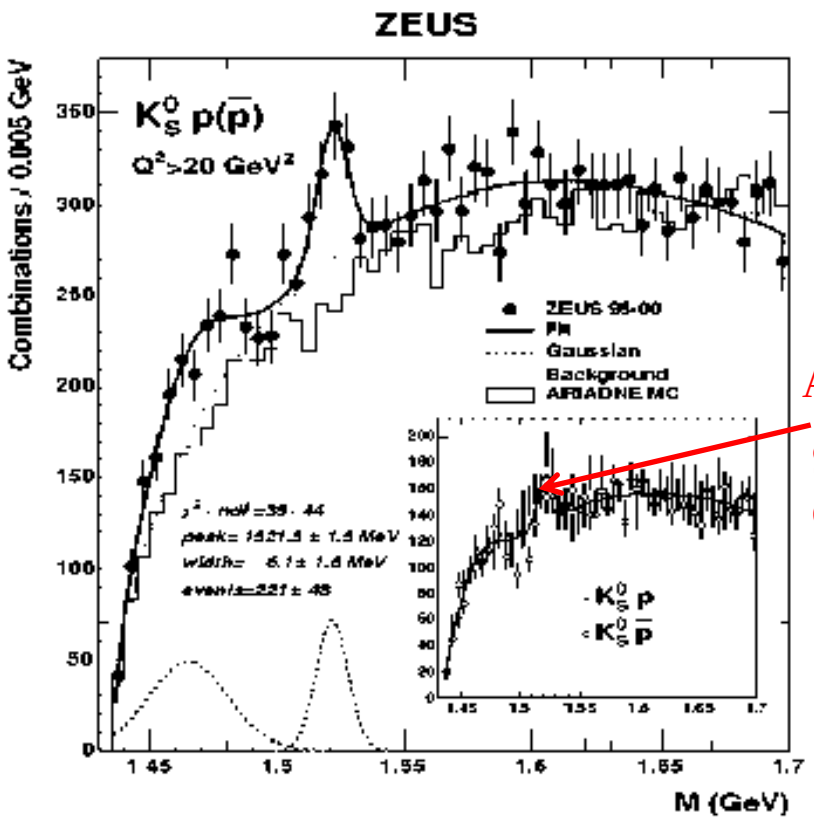
$p_t(K^0_s p)>0.5$GeV, $|\eta(K^0_s p)|<1.5$

221±48 events at M_{θ^+}=1521.5±1.5(stat)+

2.8-1.7(syst) MeV

Width σ=6.1±1.5 MeV

Significance ~4.6σ



Anti-θ^+

96±34 events

θ^+ cross section (preliminary):

$\sigma(ep \rightarrow e\theta^+ X \rightarrow eK^0_s pX)$=
125±27+36-28 pb

(MC Σ forced to decay like θ^+)

Strange pentaquark $\theta^+ \rightarrow K^0_s p$: ZEUS results

$\theta^+ \rightarrow K^0_s p$

$\Lambda(1520) \rightarrow K^{\pm} p$

forward

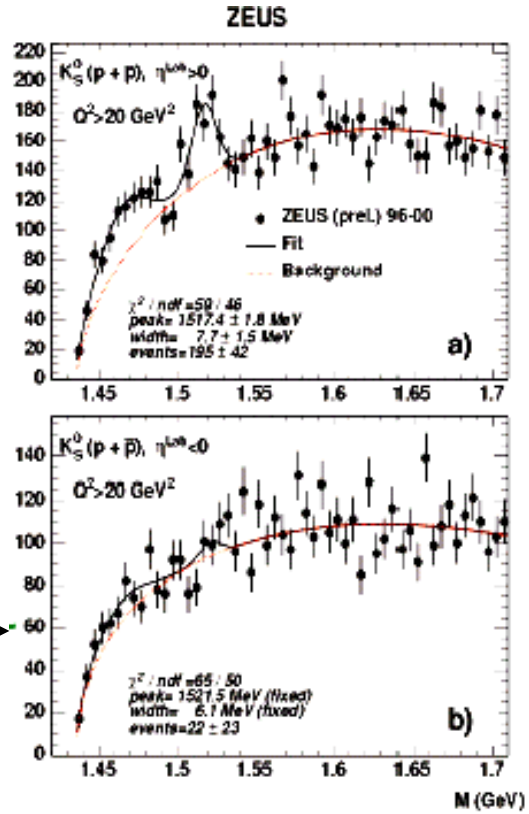
(proton direction)

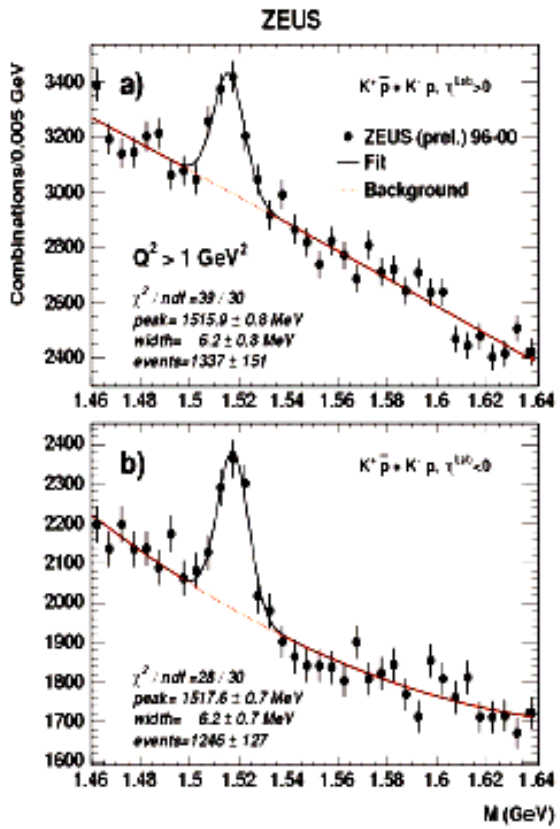
$\eta > 0$

backward

(pure fragmentation)

$\eta < 0$





θ^+ production only in forward region of central detector

(related to proton remnant?)

Strange pentaquark $\theta^+ \to K^0_s p$: H1 results

H1 1996-2000 data 74 pb^{-1}

DIS: $Q^2>20$ GeV; $0.1<y<0.6$

$\theta^+ \to K^0_s p$, $K^0_s \to \pi^+\pi^-$, p via dE/dx

$p_t(K^0_s p)>0.5$GeV, $|\eta(K^0_s p)|<1.5$

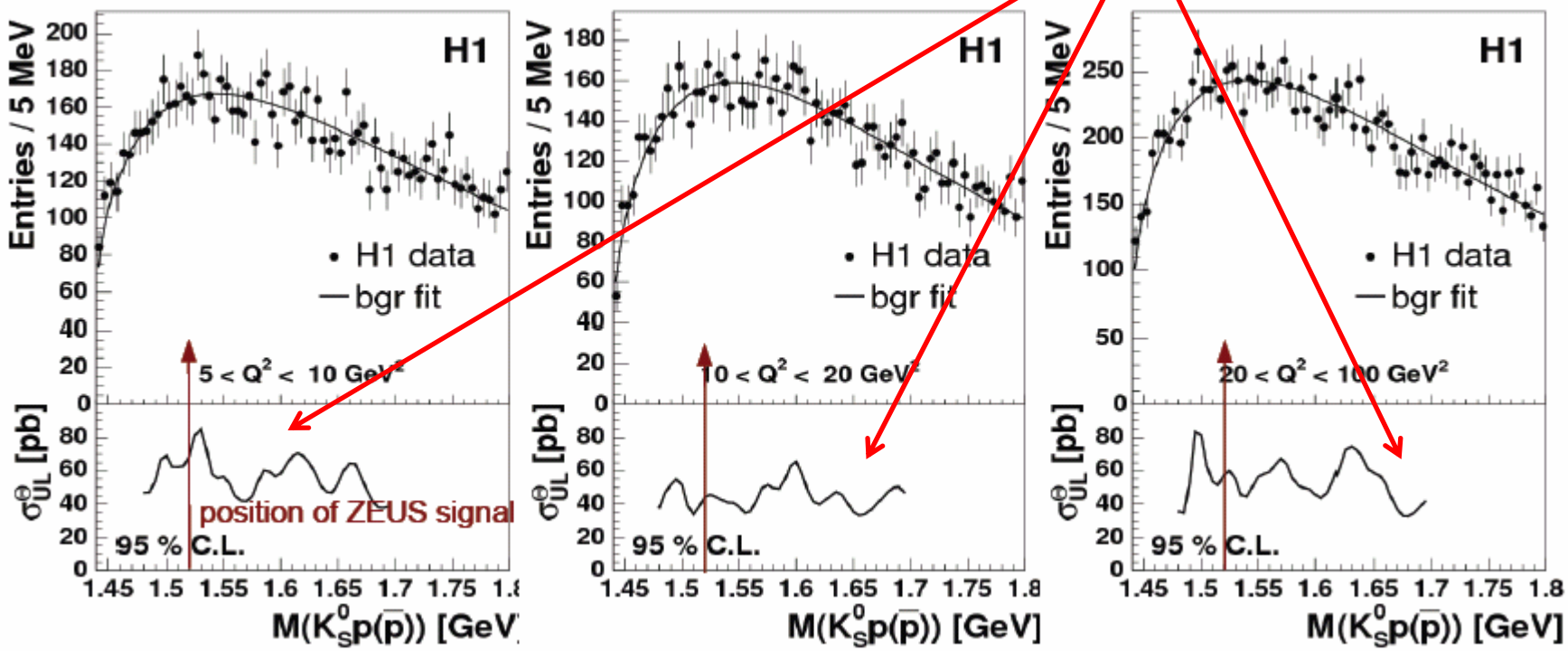
No signal observed

Upper limit at 95% c.l. at M~1.52GeV:

$\sigma(M=1.52)<72$ pb

No fluctuation of upper limit

at the same mass



Strange pentaquark $\theta^+ \rightarrow K^0_s p$: H1 results

Comparison with ZEUS

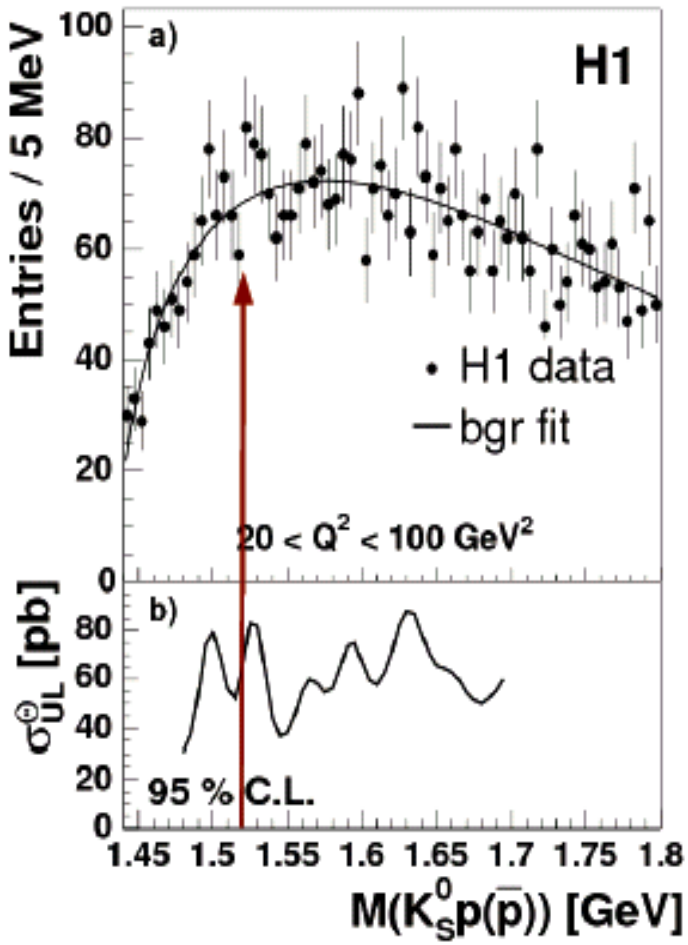
Differences:

y range:

ZEUS: $0.04<y<0.95$

H1: $0.1<y<0.6$

dE/dx selection



Upper limit at 95% c.l. at M~1.52GeV:
$\sigma(M=1.52)<72$ pb

Upper limit not in contradiction with ZEUS cross section

Charm pentaquark $\theta_c \rightarrow D^* p$: H1 results

H1 1996-2000 data 75 pb^{-1}

DIS: $1<Q^2<100\ GeV^2$; $0.05<y<0.7$

$\theta_c \rightarrow D^* p$, $D^* \rightarrow K^- \pi^+ \pi_s^+$, p via dE/dx

$p_t(D^* p)>1.5 GeV$, $-1.5<\eta(D^* p)<1$

$M_{\theta c}=3099\pm3(stat)\pm 5(sys)$ MeV

Width $\sigma=12\pm3$ MeV

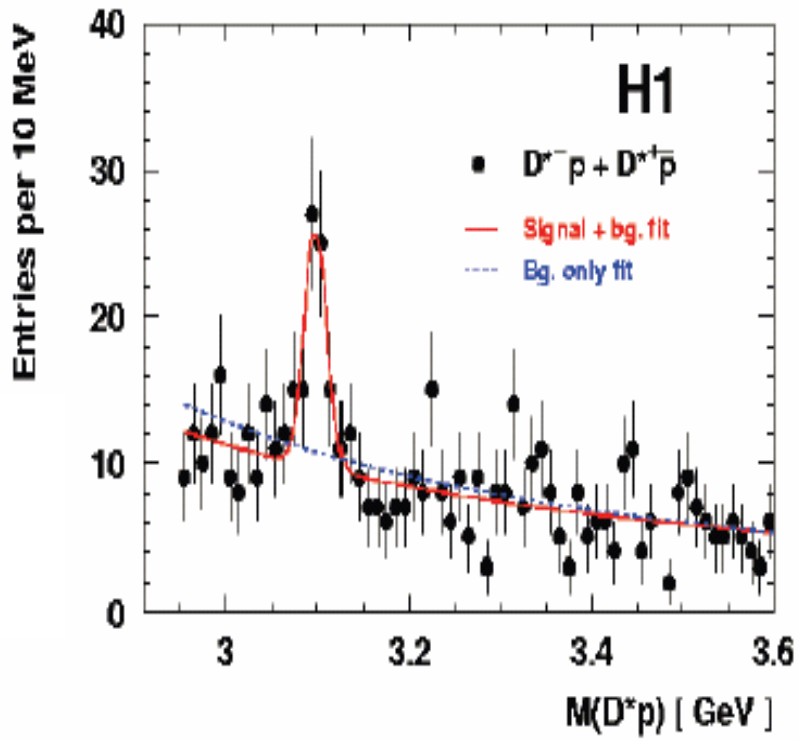
signal and bg within ± 25 MeV:

$N_{s=}50.6\pm11.2$; $N_b=45.0\pm2.8(stat.)$

Significance ~5.4σ

Acceptance corrected
ratio of cross sections:

$$R_{cor}(D^* p/D^*)=1.59\pm0.33^{+0.33}_{-0.45}\%$$



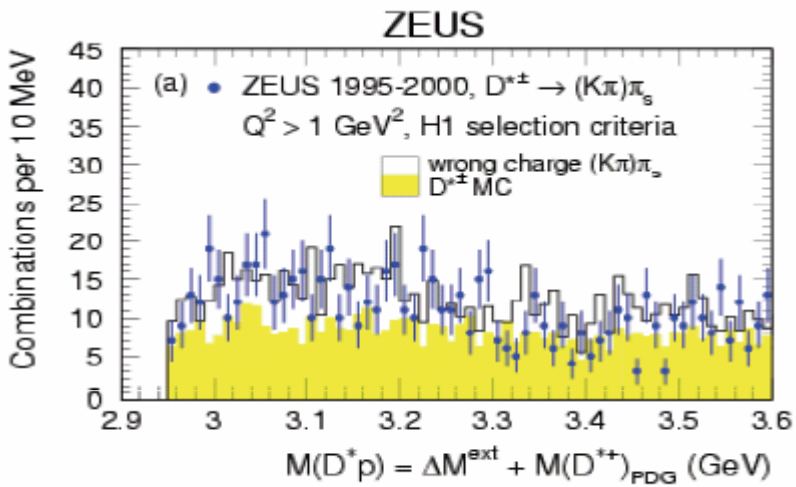
Charm pentaquark $\theta_c \rightarrow D^* p$: ZEUS results

No signal!

ZEUS 1995-2000 data 126 pb^{-1}

DIS: $1<Q^2<100$ GeV^2; $0.05<y<0.7$

$\theta_c \rightarrow D^* p$, $D^* \rightarrow K^- \pi^+ \pi_s^+$, p via dE/dx



Upper limit at 95% c.l. : $R_{cor}<0.59\%$

H1 ratio of cross sections ($R_{cor}(D^*p/D^*)=1.59\pm0.33^{+0.33}_{-0.45}\%$) excluded

but differences in selections:

ZEUS: $|\eta_D|<1.6$, $p_{t,D}>1.35$ GeV, $y<0.95$

H1: $-1.5<|\eta_D|<1$, $p_{t,D}>1.5$ GeV, $0.05<y<0.7$

Conclusions

Charged particle production

- string hadronisation (JETSET) better than cluster fragmentation (HERWIG)
- quark fragmentation universality demonstrated (e^+e^- vs ep)
- PS and CDM give similar description of the data, PS+SCI gives better description at high x_p

Strangeness production

- inclusive Λ and K^0_s cross sections best described by ARIADNE with $\lambda_s = 0.3$
- ratio of strange to charged light mesons requires $\lambda_s = 0.22$ rather than 0.3

Pentaquark production

- narrow state in $K^0_s p$ observed by ZEUS at ~1520 MeV

  $\sigma(ep \rightarrow e\theta^+X \rightarrow eK^0_s pX) = 125 \pm 27^{+36}_{-28}$ pb

  H1 does not observe signal, upper limits do not exclude ZEUS cross section

- narrow state in $D^* p$ observed by H1 at ~3099 MeV

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

  ZEUS does not confirm signal $R_{cor} < 0.59\%$