Photo- and Electroproduction of Single Hadrons and Resonances

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Neutral mesons at HERA

Strangeness production

Strange content of the sea

$K_s^0 K_s^0$ resonances

Scope

The conversion of quarks and gluons into colourless hadrons is not well described at all by QCD processes, especially for light quarks, hence hadronisation models.

HERA lags behind LEP in several of the particle production measurements.

Production studies of strange particles and observation of light resonances should contribute to the understanding of hadronisation processes.

Further, strange particles can be used to probe the proton sea content or special states of matter.

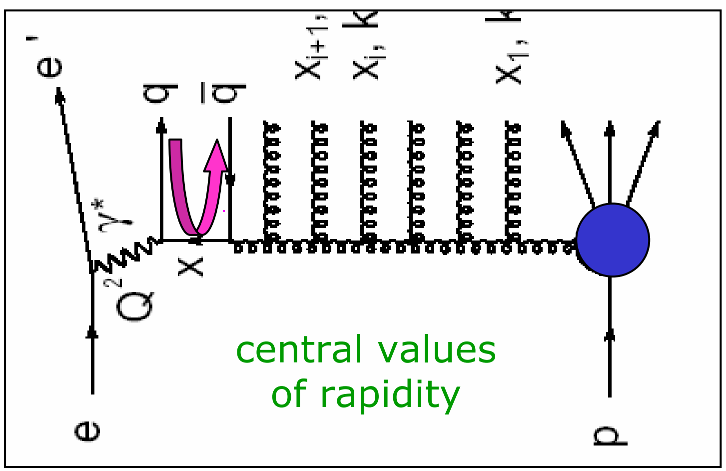
Neutral Mesons

How do quarks and gluons convert to colourless hadrons?

- *p*QCD does not apply
- phenomenological models of hadronisation

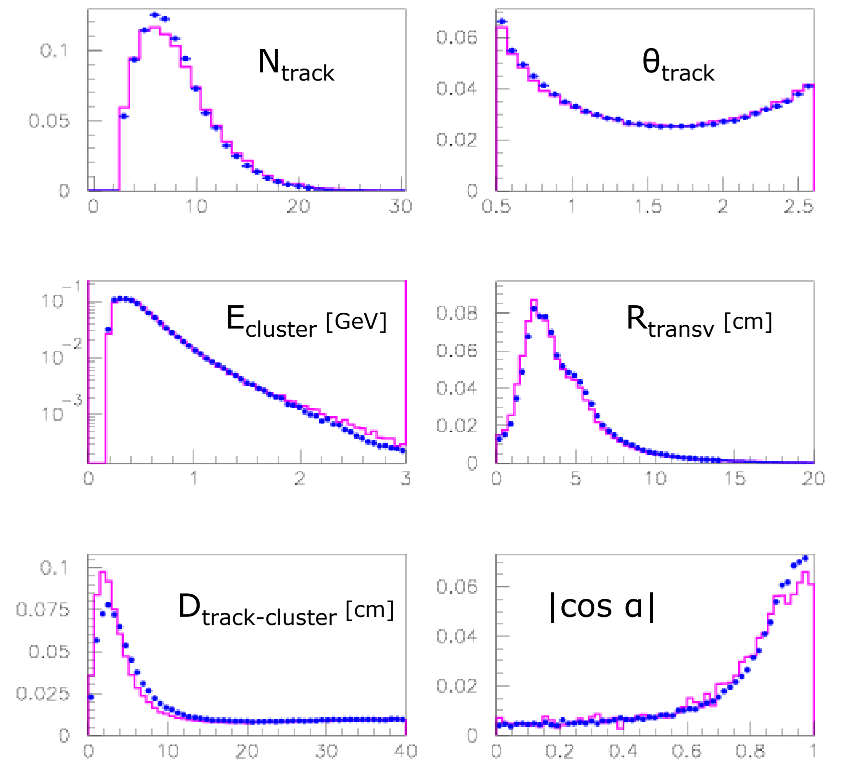
Inclusive photoproduction of neutral hadronic resonances:

η, ρ^0, $f_0(980)$ and $f_2(1270)$



Test universality of hadroproduction

H1 prel. Data vs MC (selected events)



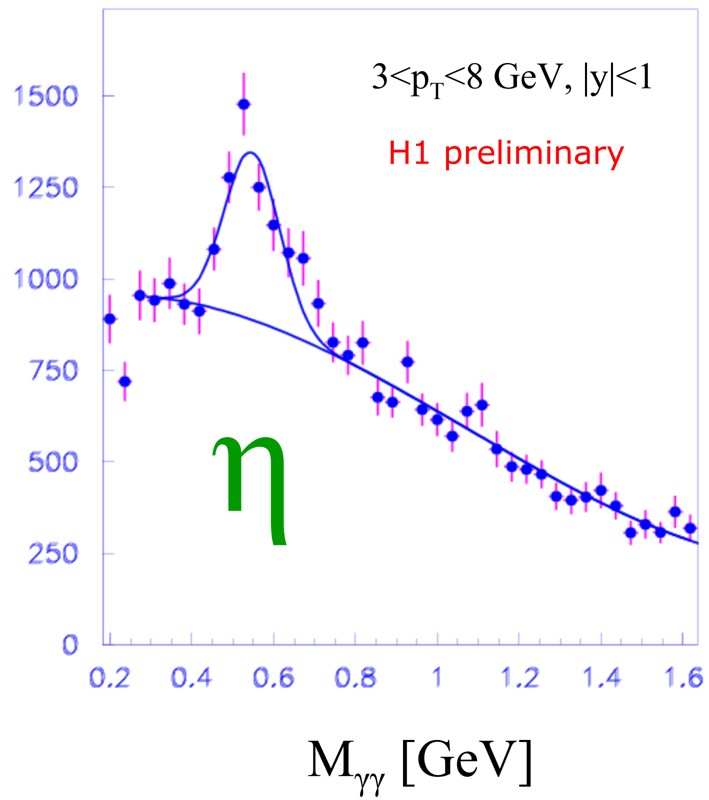
good agreement

Neutral Mesons

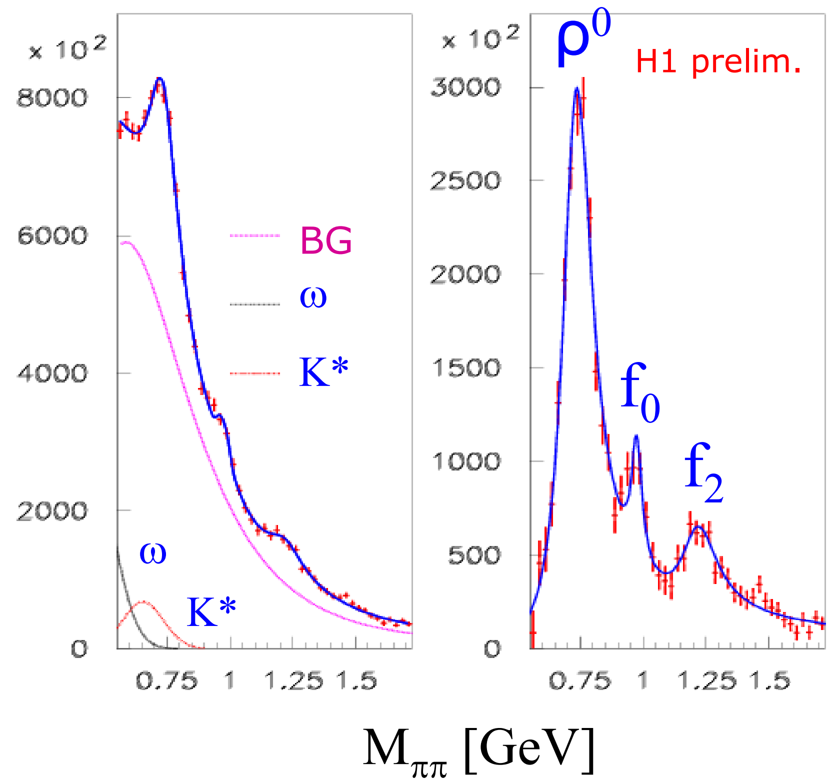
$\eta \rightarrow \gamma\gamma$ i.e. clusters in the Liquid Argon detector

$\rho^0, f_0, f_2 \rightarrow \pi^+\pi^-$ i.e. (charged) tracks in the jet chambers

} first measurements at HERA



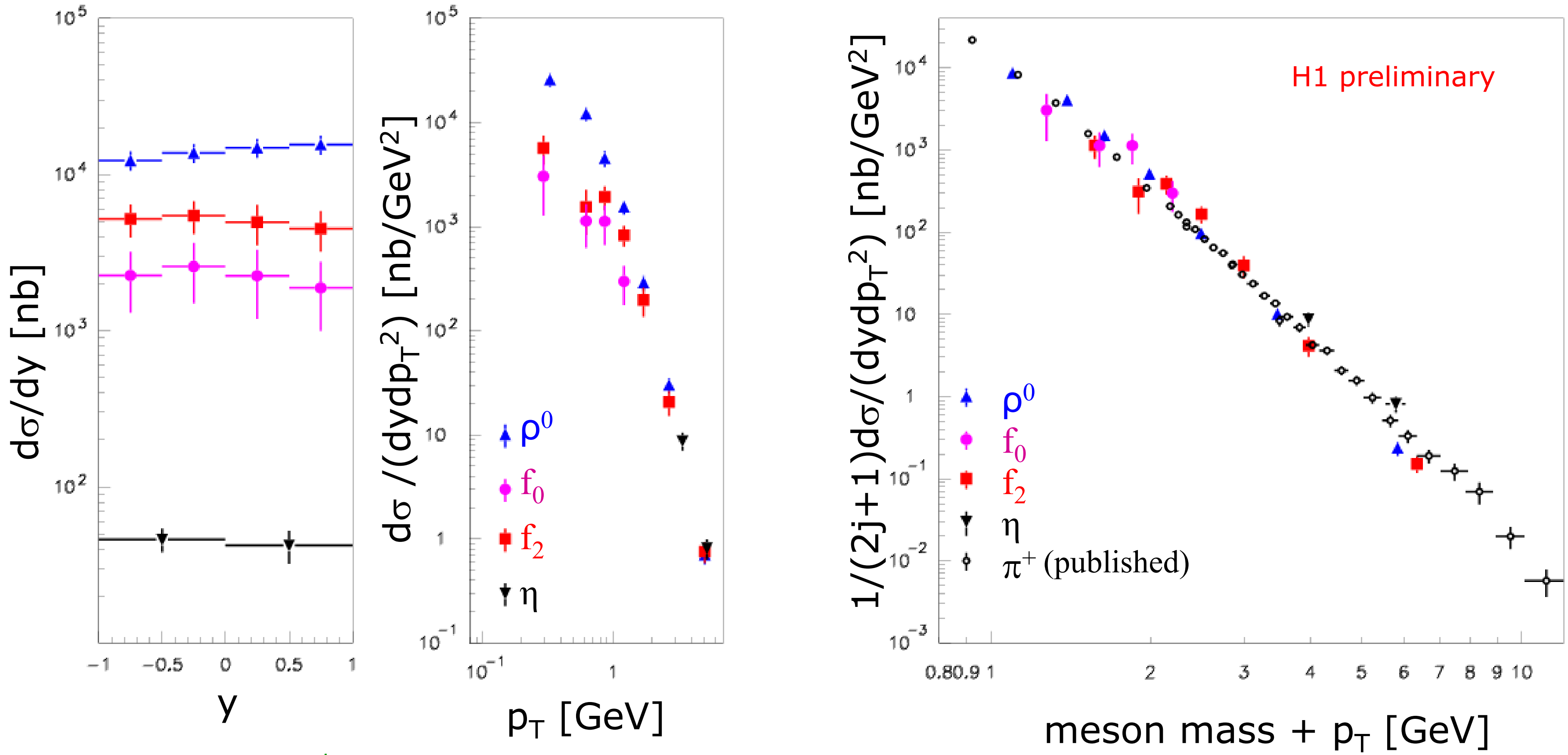
Fit: gaussian + polynomial BG



Fit: Breit-Wigner's + combinatorial BG + reflections (ω + K*)

Neutral Mesons

Differential photoproduction cross sections



2000 data: 39 pb^{-1}

$|y_{lab}| < 1$

$\langle W_{\gamma p} \rangle = 210$ GeV

Same behaviour as for light, long-lived hadrons

Strangeness Production

Strange particles have already been measured by ZEUS and H1 at HERA: K_s^0 and Λ's (1994 data)

Of special interest (clear signatures):

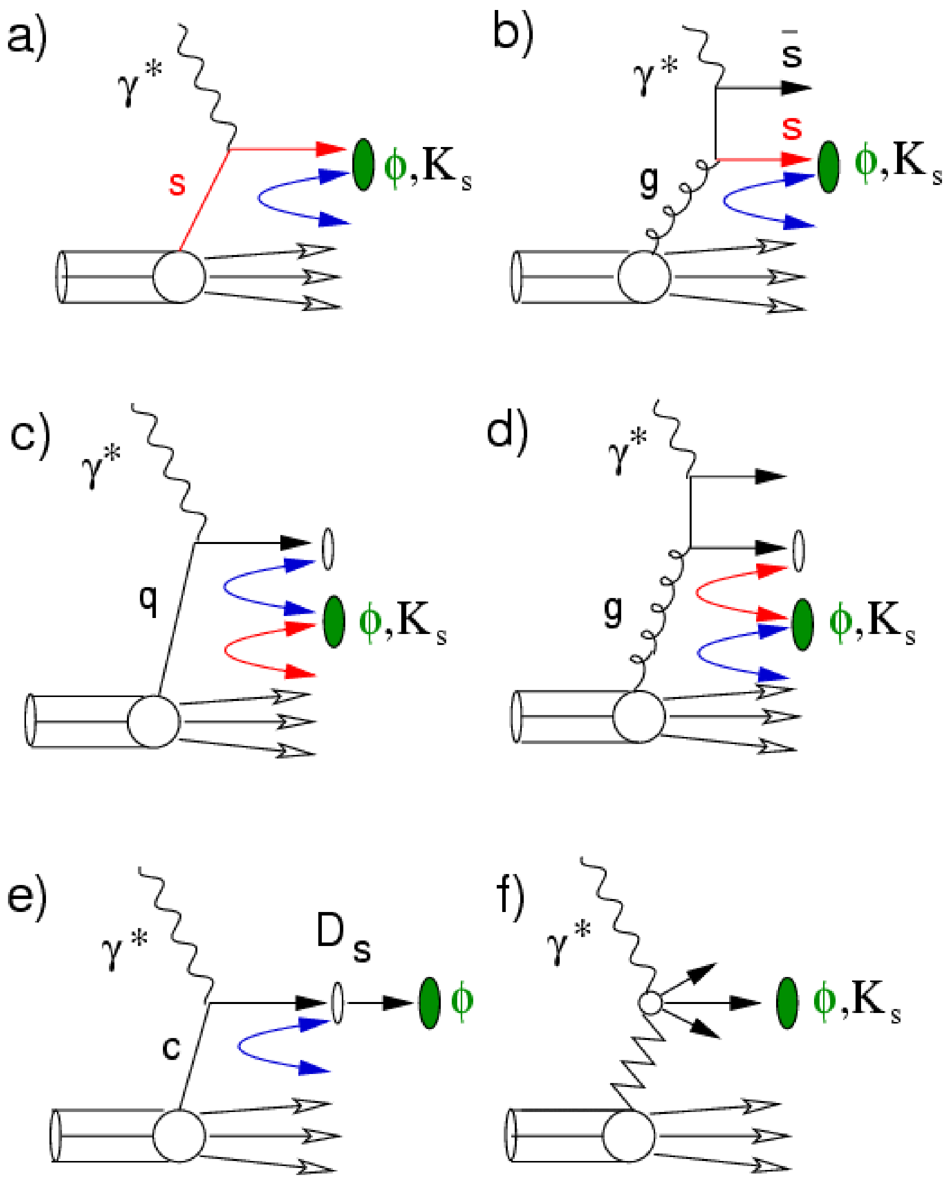
- $K_s^0 \rightarrow \pi\pi$ (BR=69%)
- $\Lambda, \bar{\Lambda} \rightarrow p\pi$ (BR=64%)
- $\phi \rightarrow KK$ (BR=49%)

} e.g. for fragmentation (K_s^0, Λ)

} e.g. for sea content (ϕ)

Rates and distributions of shapes have been measured in deep inelastic scattering and photoproduction, fragmentation functions, but no cross section had been determined.

Strangeness Production



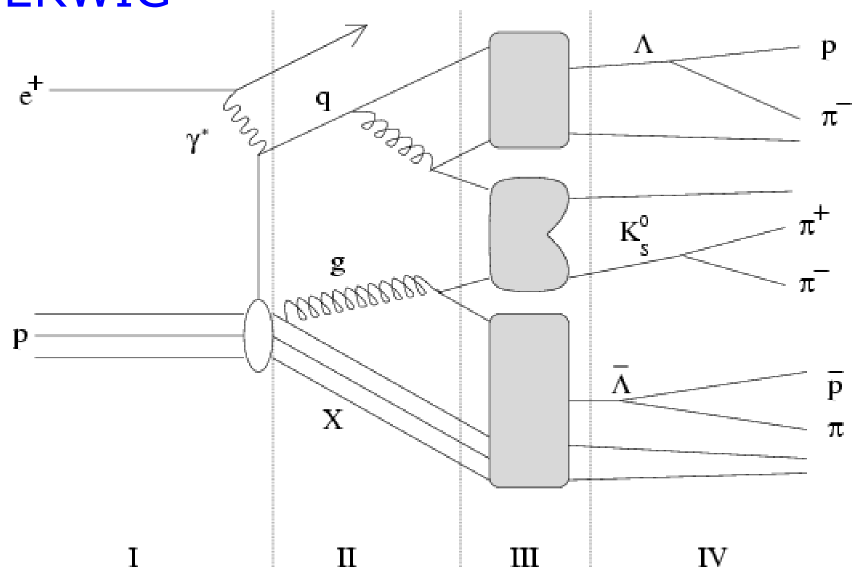
Strange quarks may come from:

- flavour excitation (a)
- QCD Compton, g-splitting (a)
- Boson-Gluon fusion (b)
- hadronisation processes (c,d)
- decay from higher-mass states (e)
- diffractive processes (f)

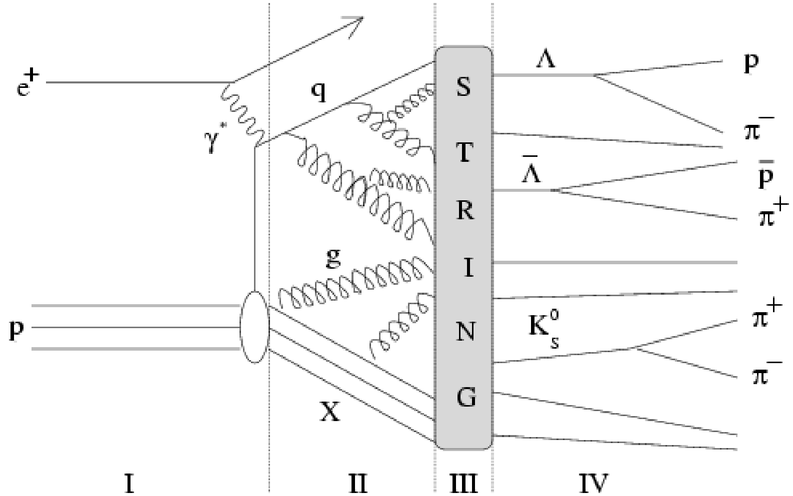
Can one differenciate?

Strangeness Production

HERWIG



ARIADNE+JETSET



DIS phases:

1 - parton evolution (e.g. DGLAP), hard scattering (PDF's)

2 - parton shower

3 - string/clusters (fragmentation)

4 - resonance decays

5 - final state hadrons (detector-level)

Fragmentation models:

in HERWIG: Cluster Fragmentation Model

in ARIADNE+JETSET: Lund String Model

Open questions:

how are strange particles *really* produced?

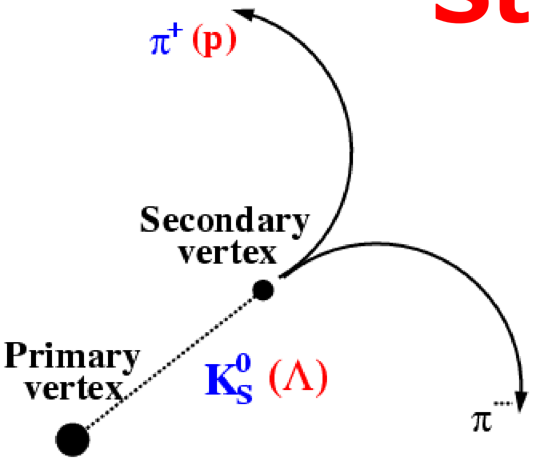
is strange particle fragmentation universal?

differences baryons *vs* anti-baryons? ..

strangeness suppression factor 0.3 (LEP)?

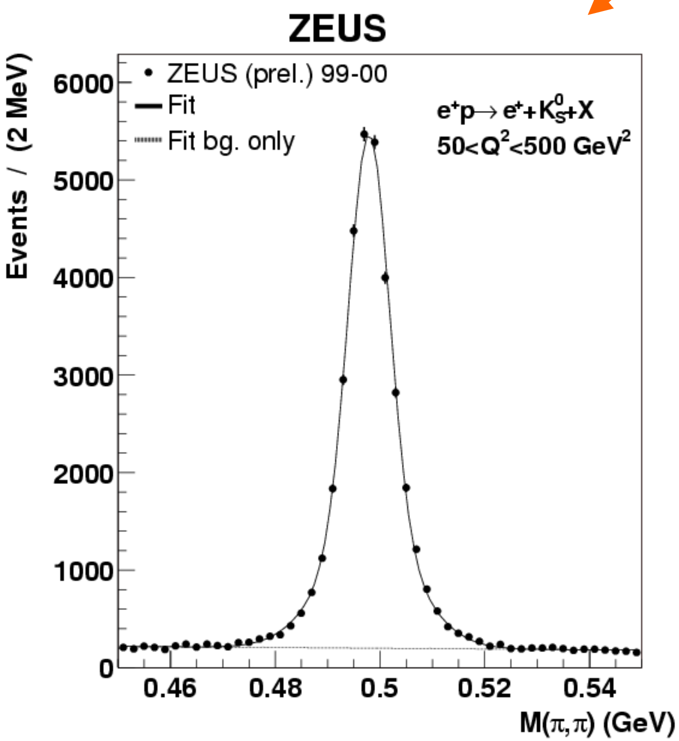
Understanding needed for the direct measurements of proton sea quarks.

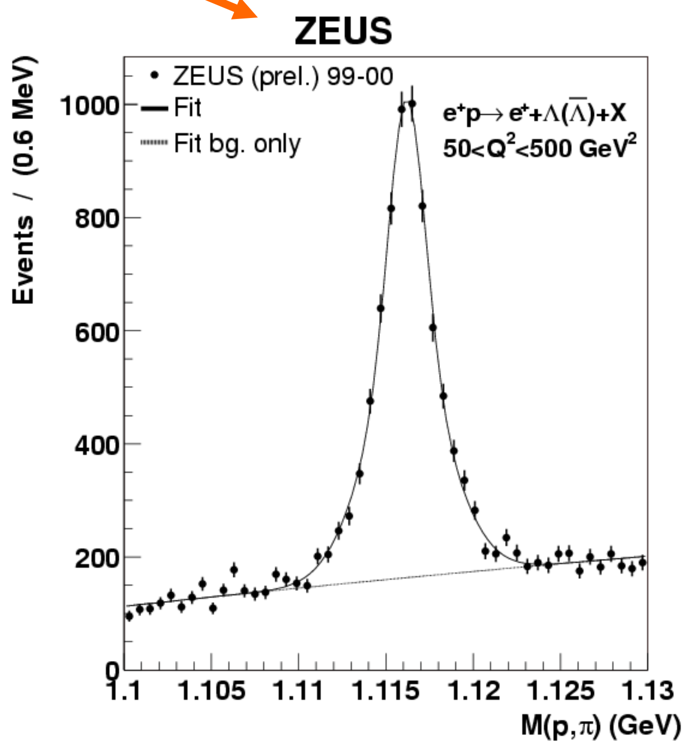
Strangeness Production



Event selection (1999-2000 data): 60 pb^{-1}

- topology: clear secondary vertex, opposite charges
- DIS: $50 < Q^2 < 500$ GeV^2 $3 \cdot 10^{-4} < x < 10^{-1}$
- K_s^0, Λ: $0.5 < p_T < 5$ GeV $|\eta| < 1.5$





clear signals

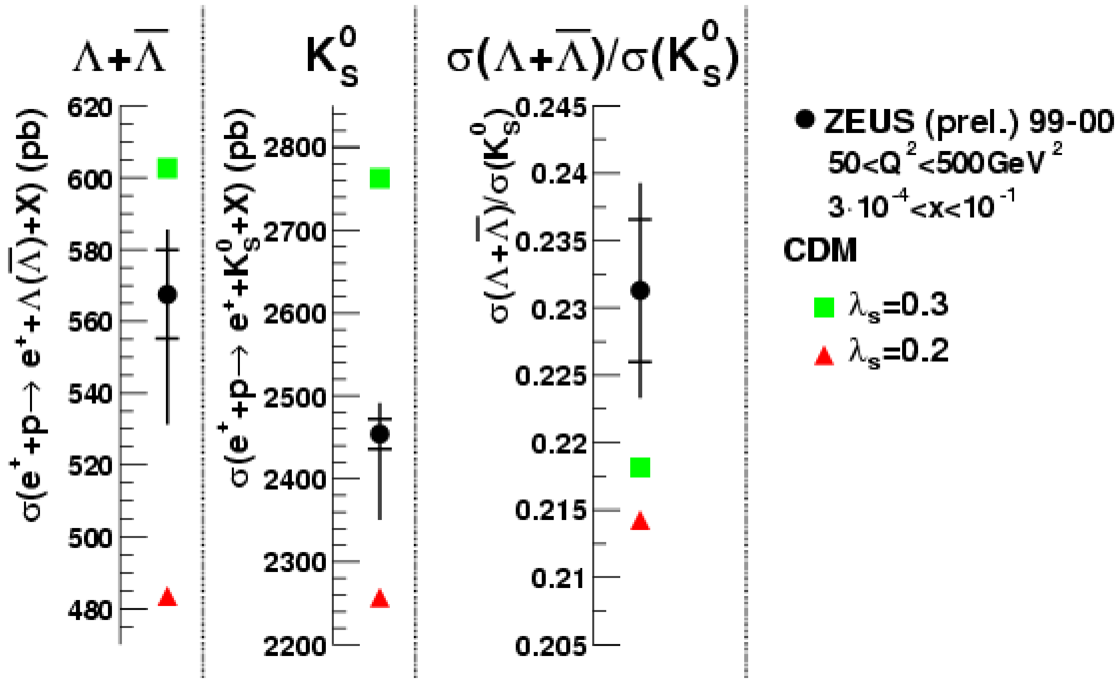
good statistics

low background

Strangeness Production

ZEUS preliminary cross sections

	$\sigma(K^0_S)$ [pb]	$\sigma(\Lambda+\bar{\Lambda})$ [pb]	$\sigma(\Lambda+\bar{\Lambda})/\sigma(K^0_S)$	$\sigma(\Lambda)$ [pb]	$\sigma(\bar{\Lambda})$ [pb]	$\sigma(\Lambda)/\sigma(\bar{\Lambda})$
ZEUS (prel.)	$2454 \pm 18^{+32}_{-102}$	$567 \pm 12^{+13}_{-34}$	$0.231 \pm 0.005^{+0.005}_{-0.006}$	$292 \pm 9^{+7}_{-18}$	$279 \pm 9^{+12}_{-18}$	$1.05 \pm 0.05^{+0.05}_{-0.05}$
CDM: λ_s=0.3	2762	603	0.218	302	301	1.00
CDM: λ_s=0.2	2257	483	0.214	240	243	0.99
HERWIG	1854	1329	0.717	661	668	0.99

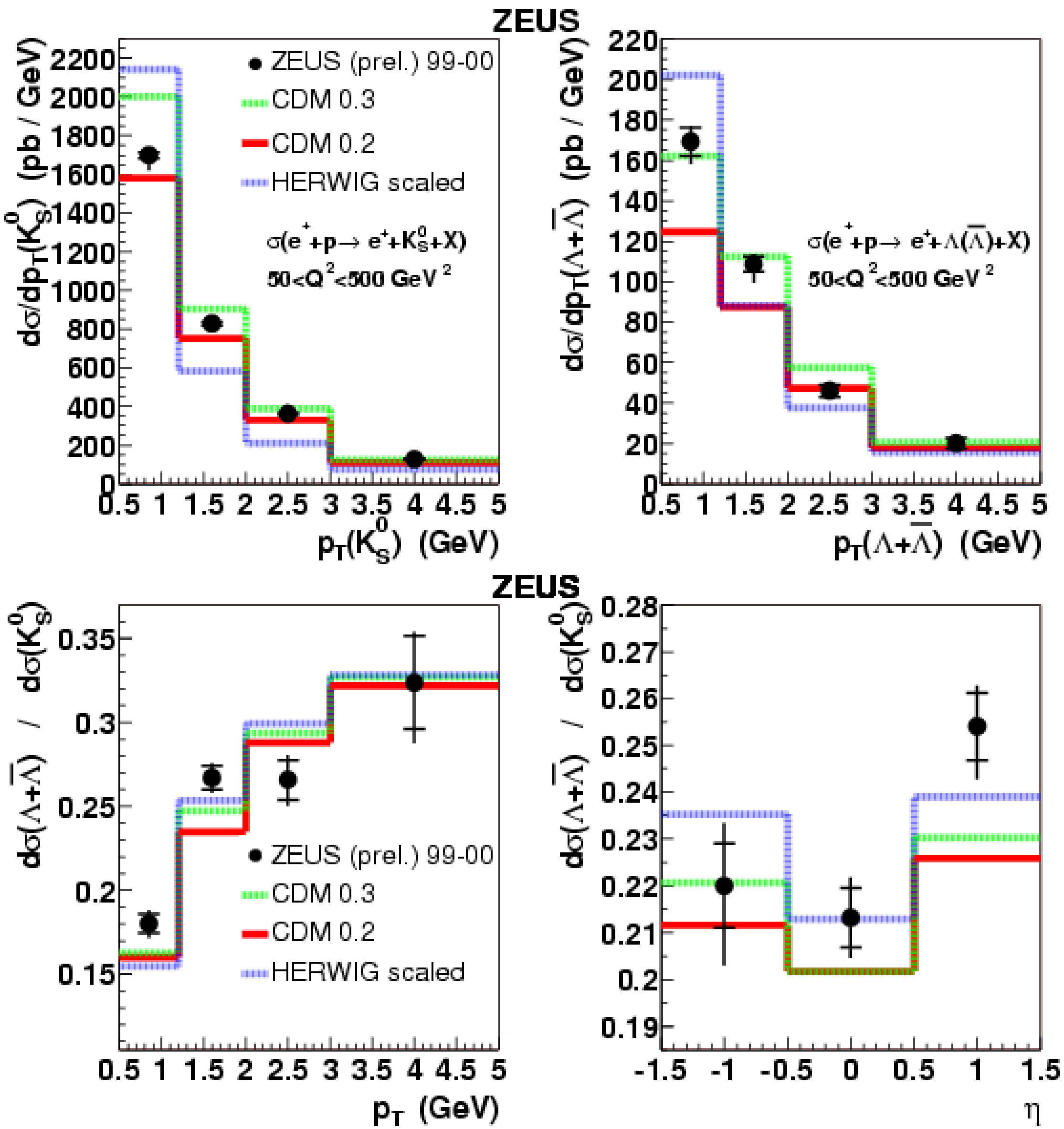


Strangeness suppression factor:

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

- Measurement falls between Lund String Model with λ_s of 0.2 and 0.3
- HERWIG fails to predict total cross sections

Strangeness Production

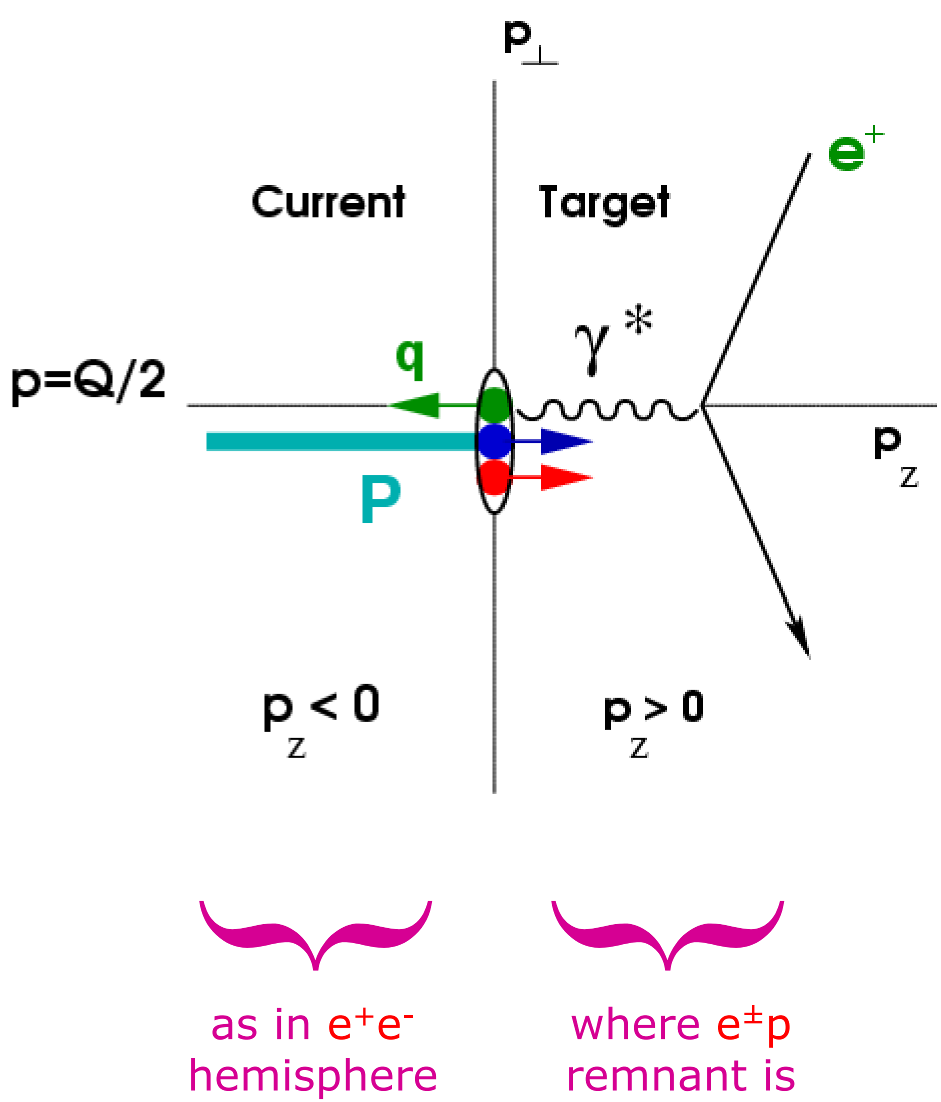


Differential cross sections in the Laboratory Frame

- renormalized HERWIG fails to reproduce the cross sections in p_T while the ratio in p_T is ~ok.
- the effect of changing λ_s is not uniform.
- from the η distribution, there is indication of increased baryon to meson production in the forward region

→ go to the Breit Frame

Breit Frame



The Breit Frame is a natural way to separate the radiation of the struck quark from the proton remnant.

Scaled momentum: $x_p = 2p/Q$

Current region ($p_z<0$)

QPM: $x_p(s) = 2p(s)/Q = 1$

1st & HO QCD: $x_p(s) \neq 1$

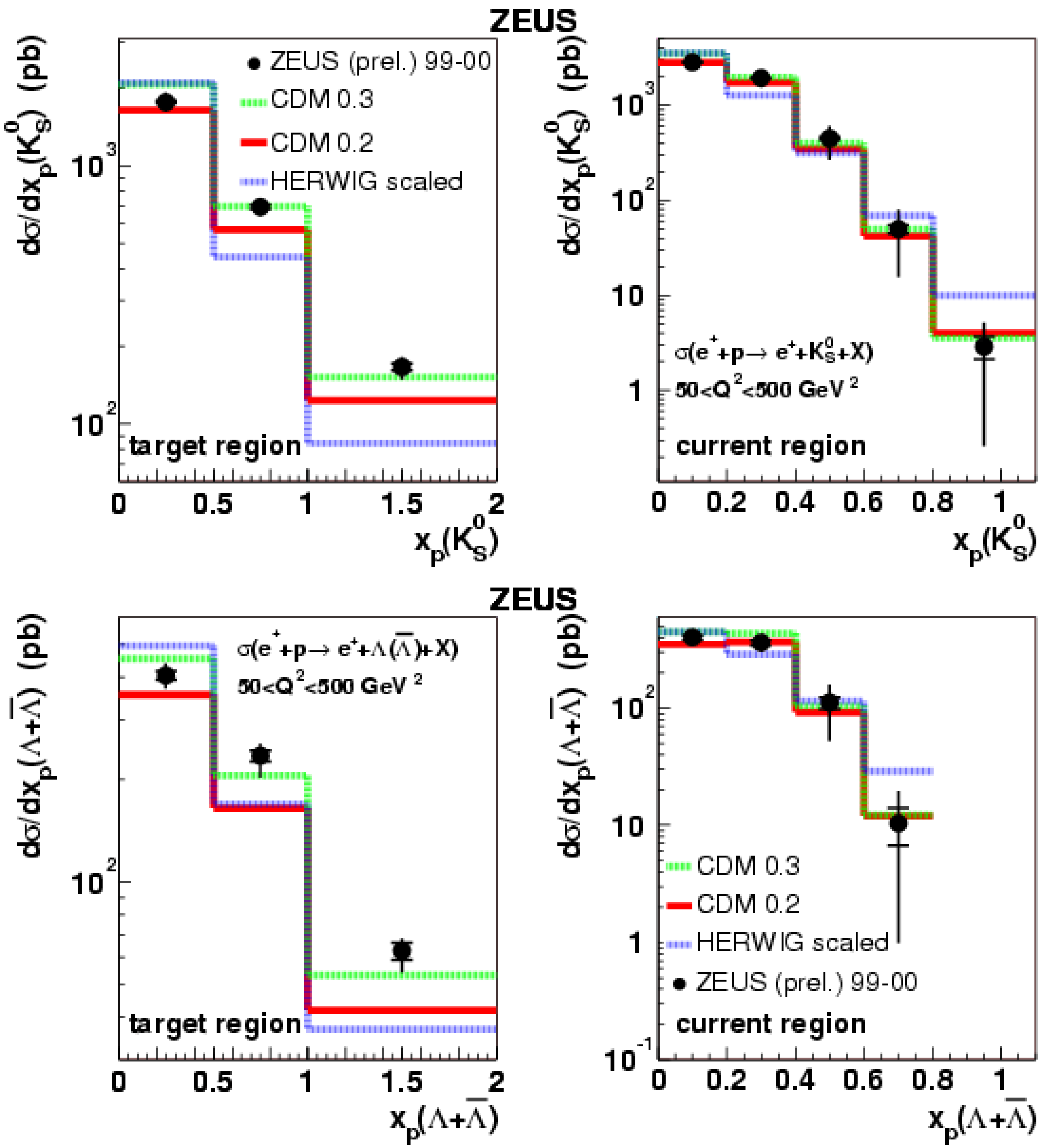
Target region ($p_z>0$)

max. remnant momentum p_R:

$$p_R \approx Q(1-x)/2x$$

$$x_p^{max} \approx (1-x)/x >> 1$$

Strangeness Production



Differential cross sections in x_p bins (Breit Frame)

target region (proton remnant):

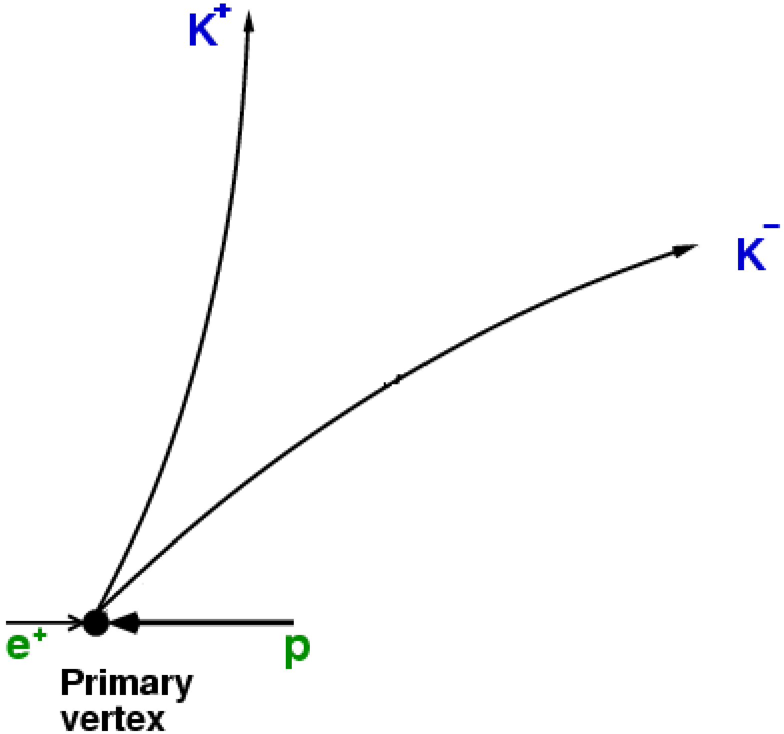
- measurements more towards λ_s = 0.3, shape problem?
- HERWIG falls too steeply

current region (like in e^+e^-):

- less sensitive to λ_s
- HERWIG does not fall steeply enough

from proton remnant region: is λ_s related to gluon density?

Strange Content of the Sea



$10 < Q^2 < 100$ GeV^2

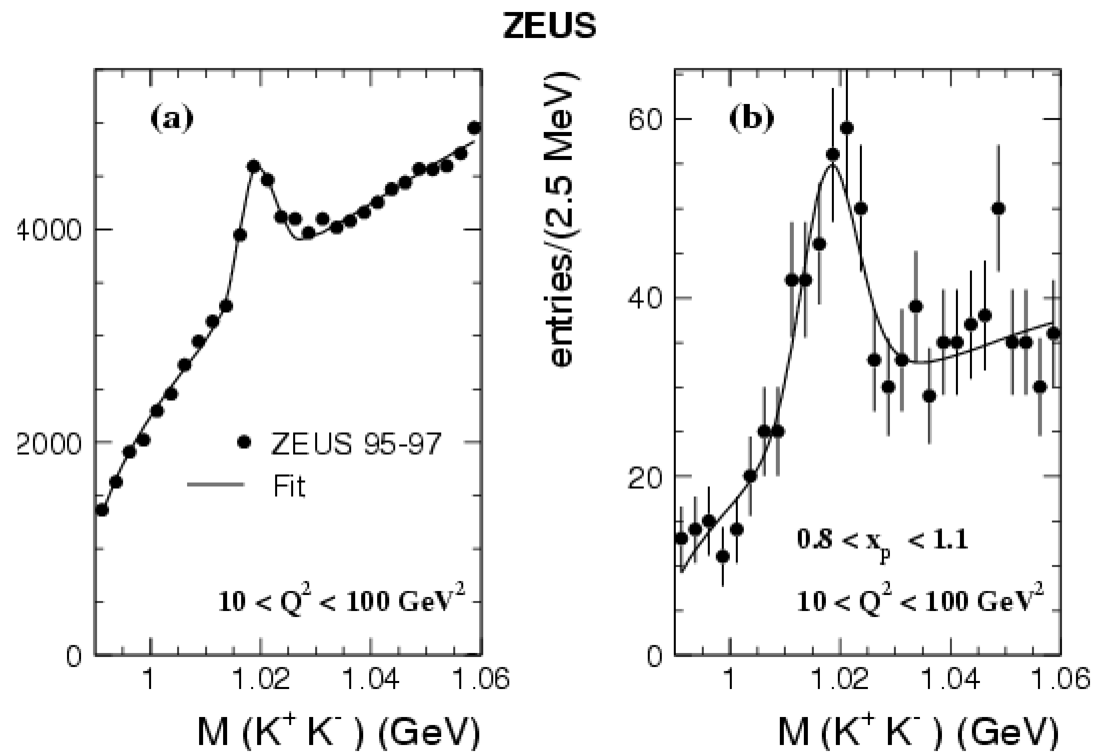
$3 \cdot 10^{-4} < x < 10^{-2}$

$1.7 < p_T < 7$ GeV

$-1.7 < \eta < 1.6$

acceptance ~45%

$\phi \rightarrow K^+K^-$ ~ at the primary vertex



Invariant mass plot

1999-2000 data: 60 pb^{-1}

(4950±214 events)

in the current region of the Breit Frame:

Fit = BW ⊗ Gaussian + BG

(181±28 leading mesons)

Strange Content of the Sea

Cross section: $\sigma(e^+p \to e^+\phi X) = 0.507 \pm 0.022(\text{stat.}) +0.010/-0.008(\text{syst.})$ nb

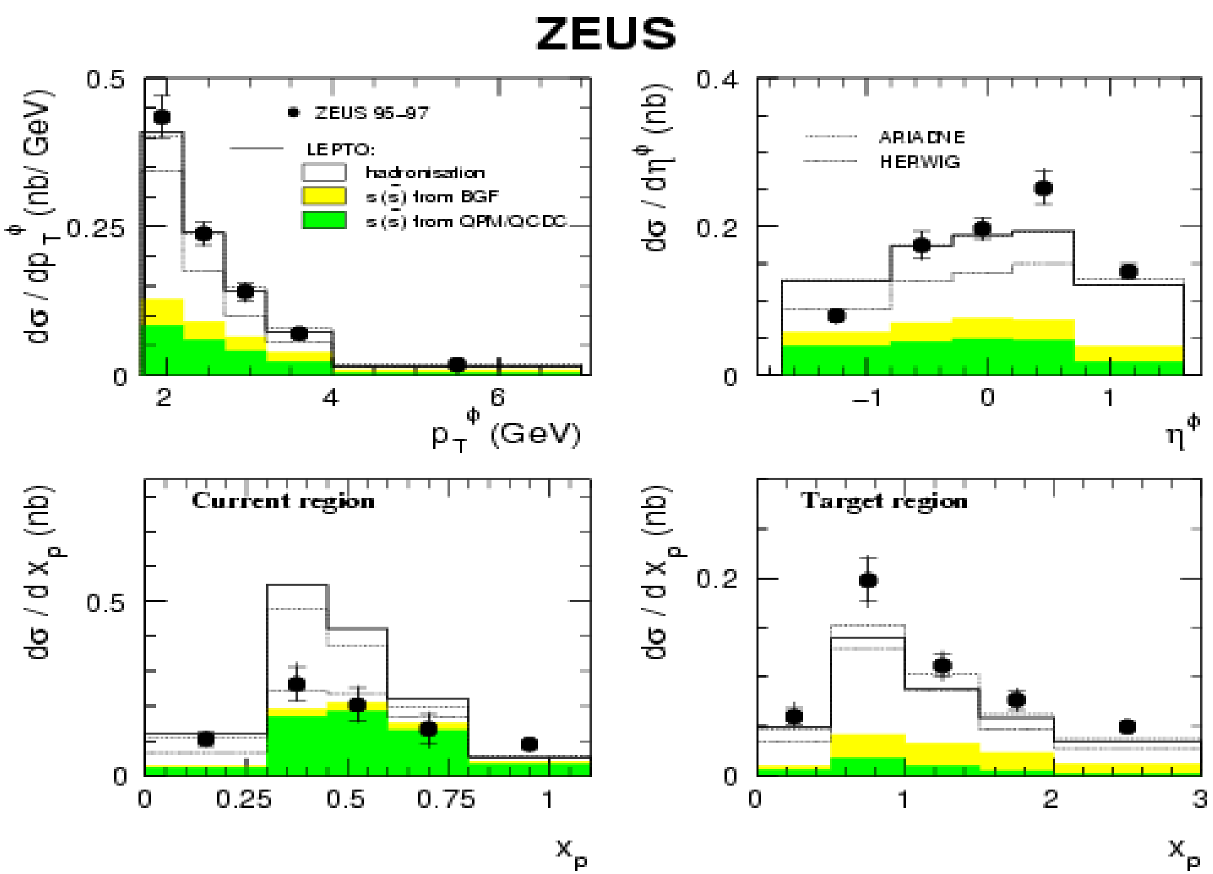
$= 0.501$ (LEPTO, $\lambda_s = 0.22$)
$= 0.509$ (ARIADNE, $\lambda_s = 0.22$)
} $\lambda_s = 0.22 \pm 0.02$

Differential cross sections:

CTEQ5D parton density

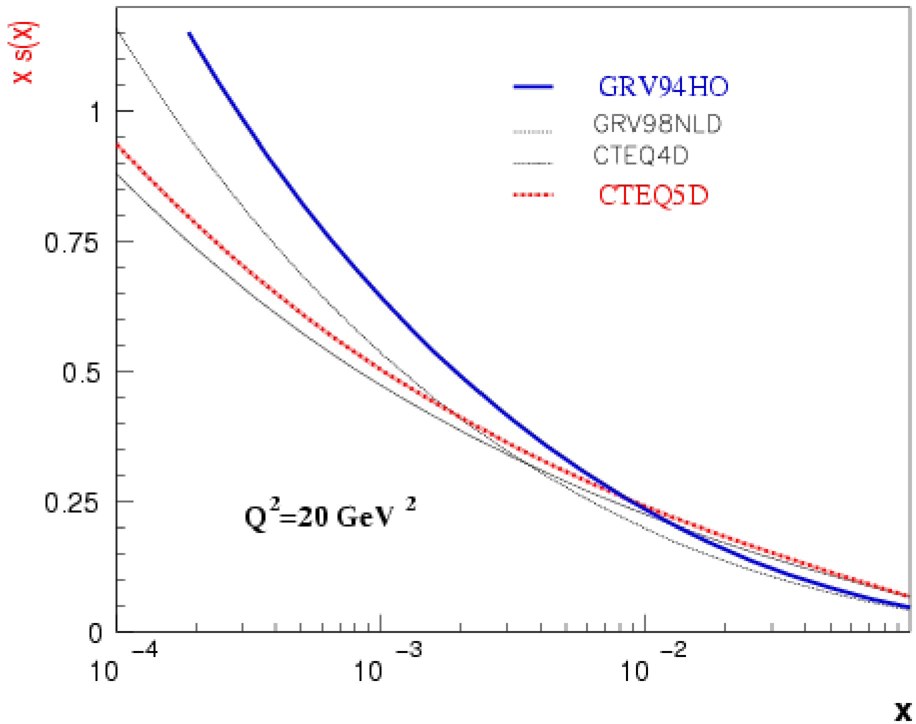
Hard QCD processes:

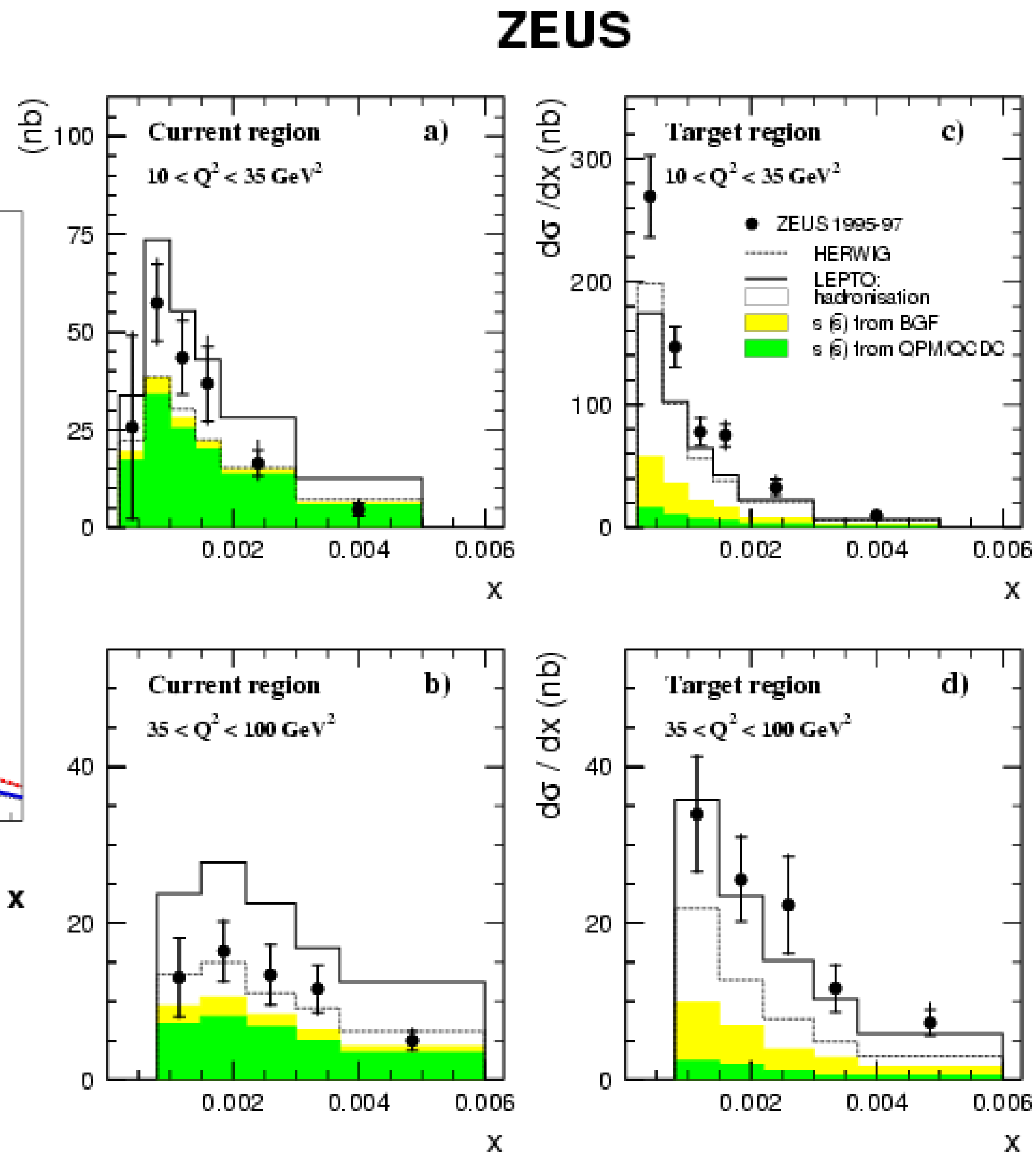
- sea s-quarks involved
- fraction increases with p_T
- significant in current region
- vanishing in target region



Strange Content of the Sea

x-analysis

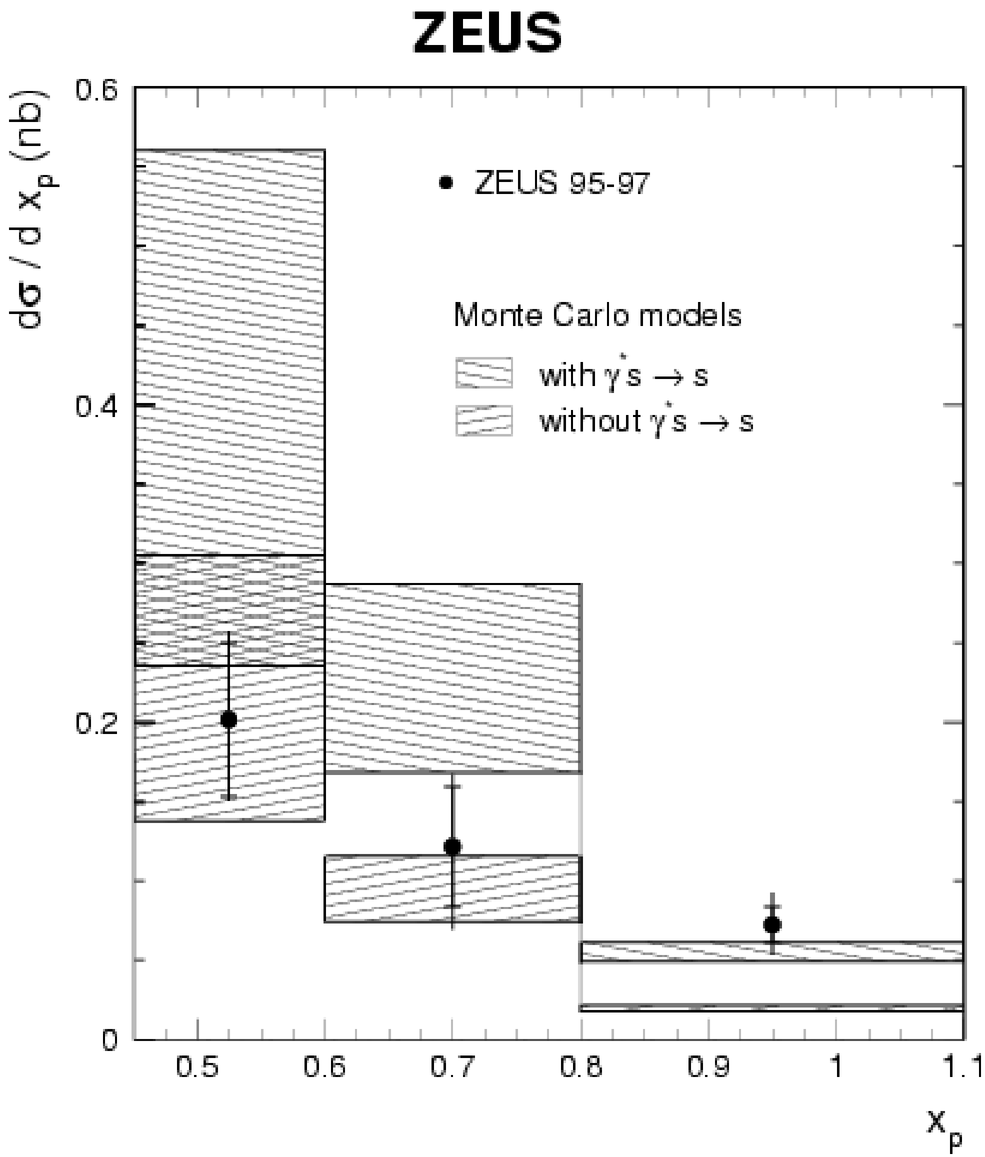




for x ⇕ s-quark density ⬀
BGF contribution ⬀ also

rise is reproduced in the data, especially BGF in target region

Strange Content of the Sea



Leading ϕ mesons (x_p>0.8)

- high p_T means small uncertainties in QCD processes and hadronisation
- QED scattering description $\gamma^* s \to s$
- additional g-emissions not relevant

Uncertainties from:

- MC models (LEPTO,ARIADNE,HERWIG)
- $\lambda_s \in$ [0.2-0.3]

Leading ϕ mesons show evidence of contribution from the strange sea in the proton at low x.

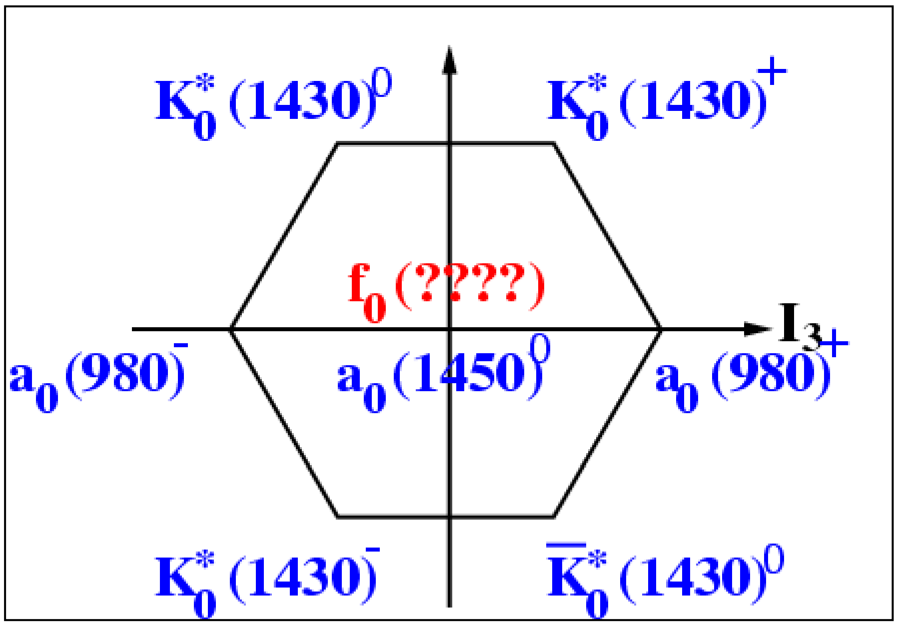
$K_s^0 K_s^0$ resonances

QCD predicts glueballs states as hadrons made up from gluons

Lattice QCD calculations set the lightest at **1730±100 MeV** ($J^{CP}=0^{++}$)

The $K_s^0 K_s^0$ system is expected to couple to $\mathbf{0^{++}}$ and $\mathbf{2^{++}}$ glueballs

The scalar 0^{++} nonet:



3 ($I=0$) candidates for 2 spots:

- $f_0(1370)$
- $f_0(1500)$
- $f_0(1710)$ glueball candidate

↓

observed, **J=0** from WA102

g-content not yet established

L3 reported 2 states at 1525(f_2') and 1760 MeV(?)

$K_s^0 K_s^0$ resonances

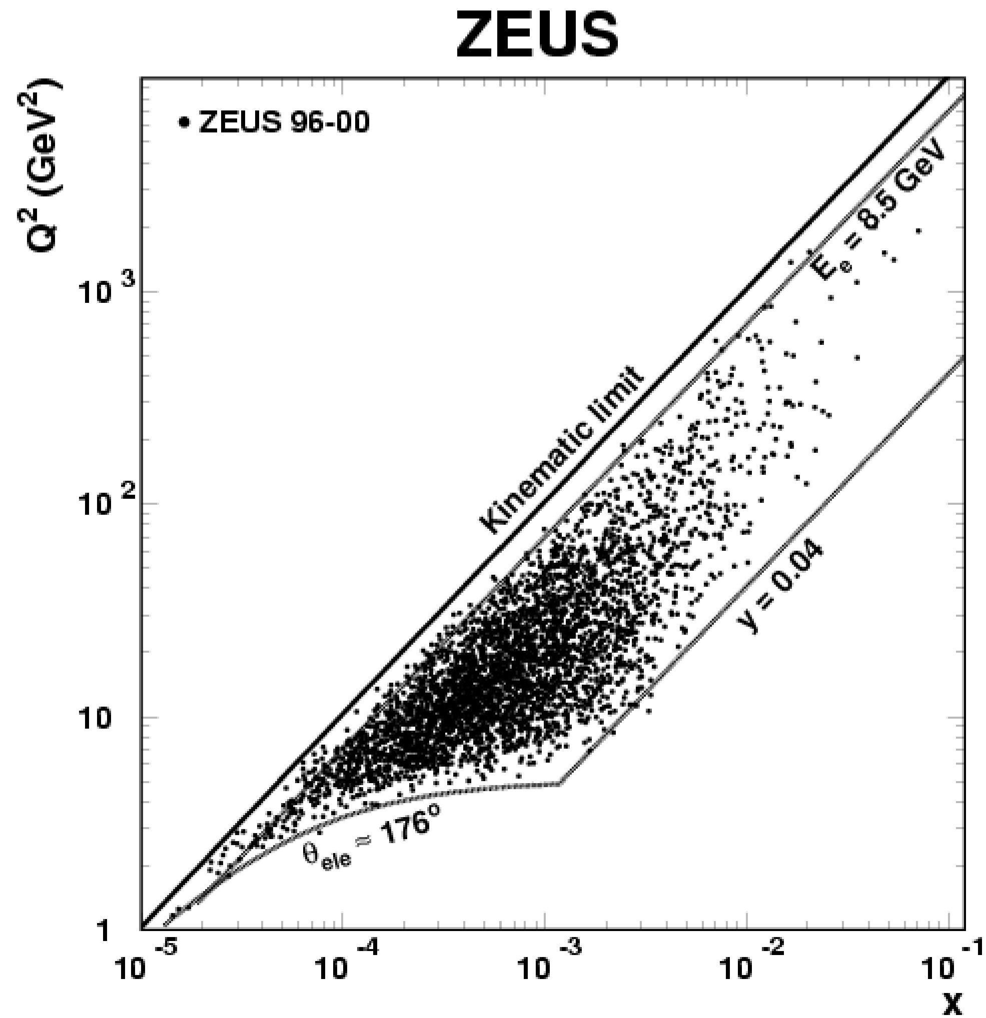
ZEUS 1996-2000 data: integrated luminosity = 121 pb^{-1}

$0.04 \leq y \leq 0.95$

$E_e \geq 8.5$ GeV

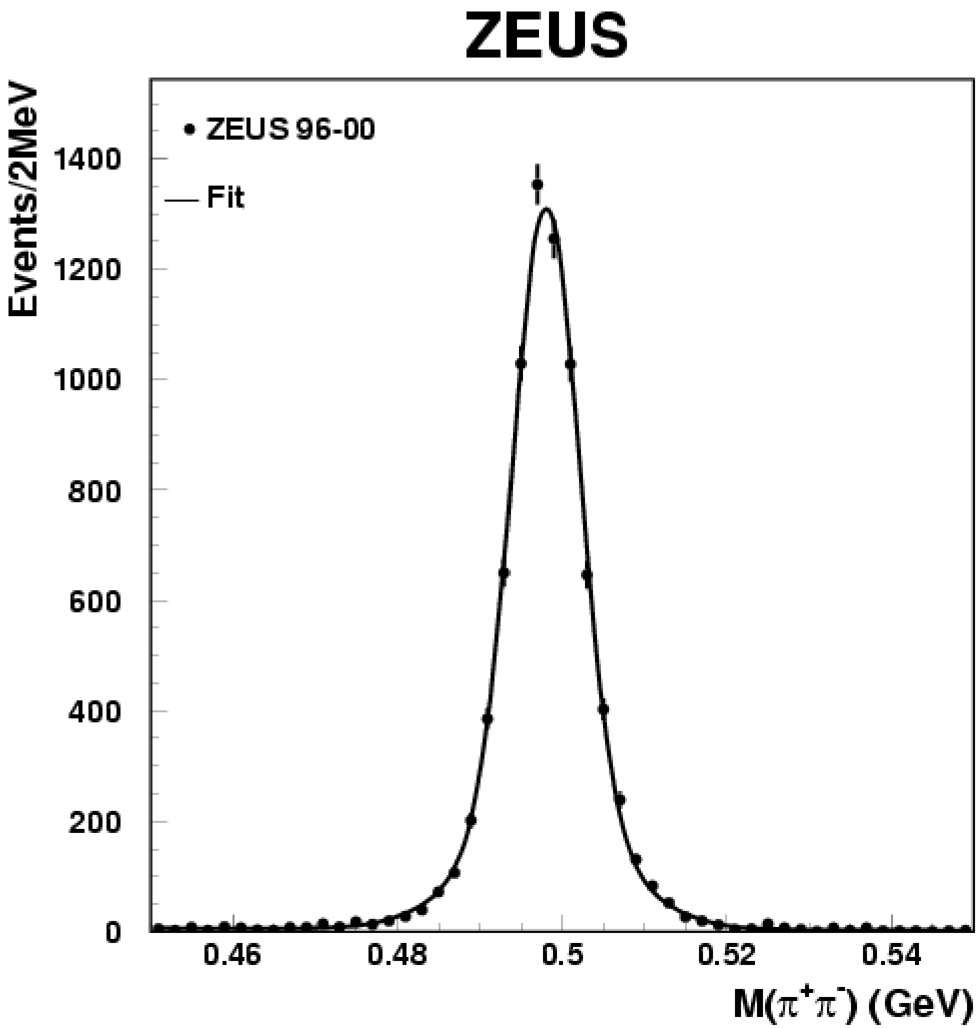
box cut on RCAL: ±14 cm

+ other background
  reduction cuts



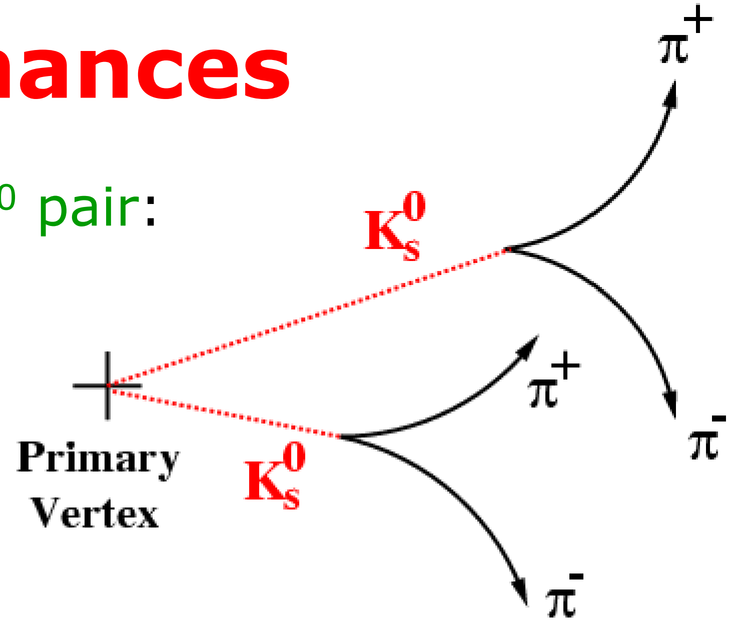
$K_s^0 K_s^0$ resonances

K_s^0 candidate selection:



Fit = 2 Gaussian + linear BG

K_s^0 pair:



$-1.75 < \eta_\pi < 1.75$

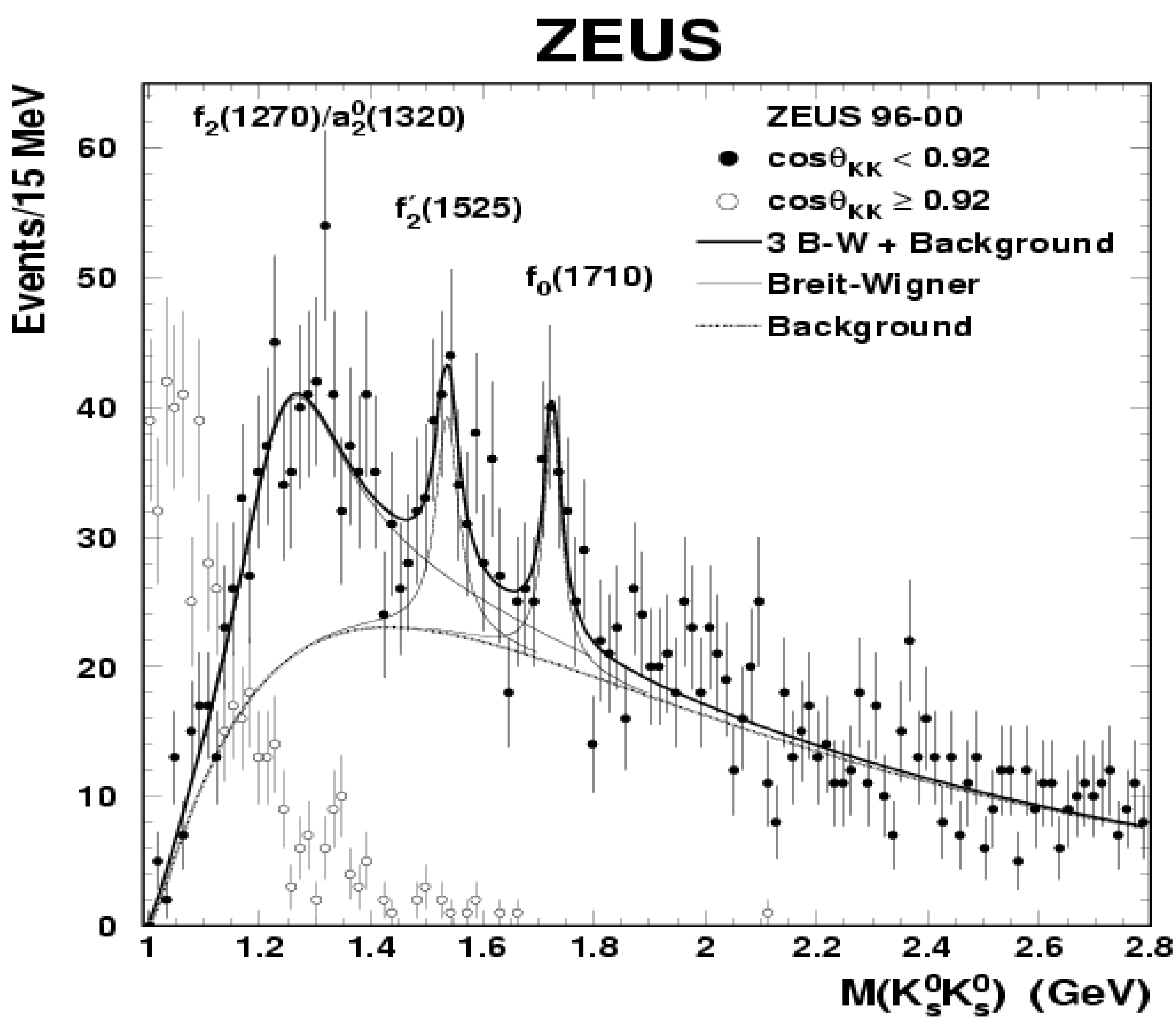
$p_T(K_s^0)$ > 200 MeV

cos θ_{KK} < 0.92 (980-state rejection)

+ other cleaning cuts

2553 candidates found

$K_s^0 K_s^0$ resonances



Fit: 3 relativistic mod. B-W distributions + BG

<1500 MeV: contributions from $f_2(1270)/a_2^0(1320)$

at 1537±9 MeV: consistent with $f_2'(1525)$ state (width ~ 50 MeV)

at 1726±7 MeV: is it the $f_0(1710)$ state? (width ~ 38 MeV)

$K_s^0 K_s^0$ resonances

Discussion

ZEUS: state at 1726±7 MeV

width of 38^{+20}_{-14} MeV

74^{+29}_{-23} events

BES: 1722±17 MeV, width ~167

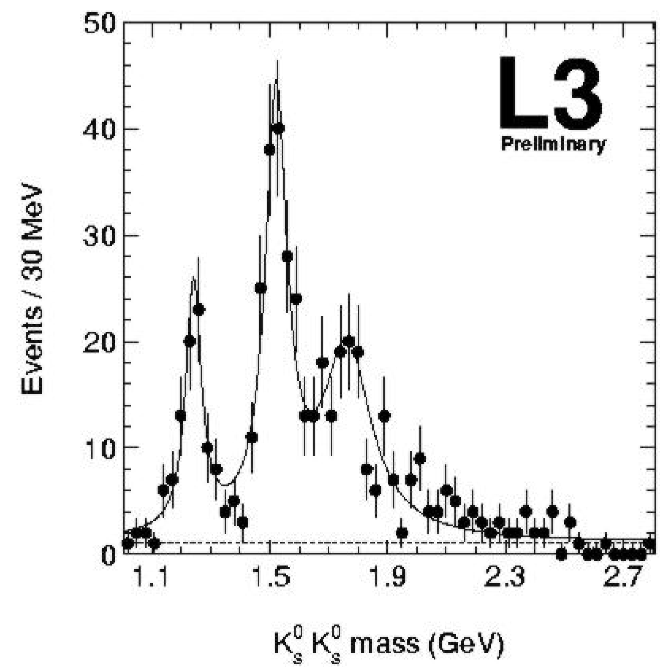
Belle: 1768±10 MeV, width ~323

PDG: $f_0(1710)$ has width 125±10 MeV

Correlations were studied by fixing widths to PDG values: still good fits

Breit Frame studies: 93% of candidates are in the target region, where the proton remnant is (i.e. sizeable initial state gluon radiation expected).

The $K_s^0 K_s^0$ Mass Spectrum



	f_2-a_2	$f_2'(1525)$	1750 MeV
Mass (MeV)	—	1523±8	1765±22
Width (MeV)	—	89±37	200±50
Events	75±15	184±27	171±26

- ❑ $f_2 - a_2$ destructive interference
- ❑ Clear $f_2'(1525)$ signal
- ❑ Clear enhancement in the 1750 MeV region
- ❑ No signal in the $\xi(2230)$ region

PHOTON 99
Freiburg, Germany

The $K_s^0 K_s^0$ Final State
in Two-Photon collisions and Glueball Searches (page 13)

Sepehr Saremi

Summary

First measurement of inclusive photoproduction cross sections of light resonances η, ρ^0, f_0(980) and f_2(1270). Features similar to those of other light, long-lived hadrons.

Strangeness production (K_s^0,Λ) is well described by MC models with λ_s~0.22, but ~0.3 in target region of Breit Frame (as at LEP). HERWIG is inconsistent with data.

ϕ-mesons provide direct evidence of the strangeness content of the proton sea.

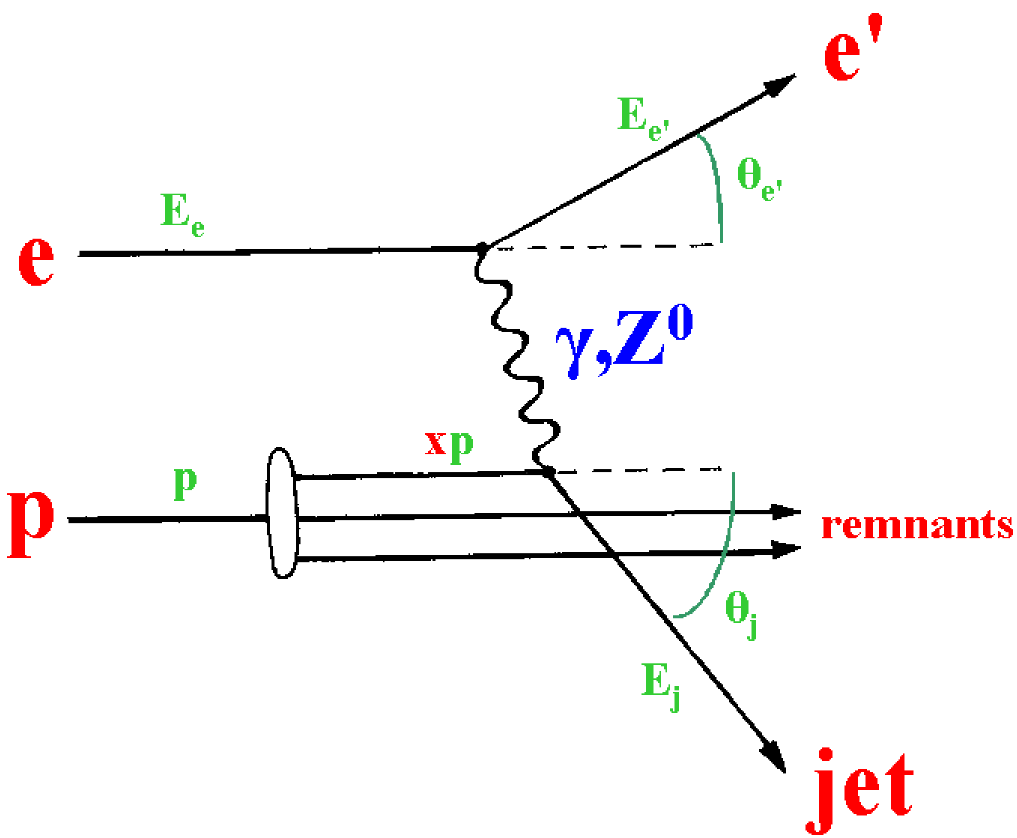
First observation of resonant $K_s^0K_s^0$ final states in DIS at 1537 MeV (f_2'?) and 1726 MeV (glueball candidate).

Particles

Particle	QPM	Mass [GeV]	$J^{P(C)}$	cτ [cm]	Decay Mode	Branching Ratio
η	*(uds)*	0.547	0^{-+}		$\gamma\gamma$	39%
ρ^0	*(ud)*	0.770	1^{--}		$\pi^+\pi^-$	~100%
f_0	*(uds)*	0.980	0^{++}		$\pi^+\pi^-$	78%
ϕ	*(uds)*	1.019	1^{--}		K^+K^-	49%
f_2	*(uds)*	1.270	2^{++}		$\pi^+\pi^-$	85%
f_2'	*(uds)*	1.525	2^{++}		KK	89%
f_J	*(uds)*	1.710	0^{++}		KK	?
K_s^0	*ds*	0.497	0^-	2.68	$\pi^+\pi^-$	69%
Λ	*uds*	1.116	$\frac{1}{2}^+$	7.89	$p^+\pi^-$	64%
$\Sigma^\pm$	*uus,dds*	1.385	$\frac{1}{2}^+$		$\Lambda\pi^\pm$	88%
Ξ^-	*dss*	1.321	$\frac{1}{2}^+$	4.91	$\Lambda\pi^-$	~100%
Ω^-	*sss*	1.672	$1\frac{1}{2}^+$	2.46	ΛK^-	68%

Deep Inelastic Scattering

$$ep \rightarrow e'X$$



$\sqrt{s}$ = center of mass energy

$q = e - e'$

$Q^2 = -q^2 = sxy$

$x = Q^2 / (2pq)$

$y = (p \cdot q)/(p \cdot e)$

rapidity: $y = \frac{1}{2} \ln \frac{E - p_z}{E + p_z}$

pseudirapidity: $\eta = -\ln(\tan\frac{\theta}{2})$