Strangeness Production and Hadron Spectroscopy at HERA

- Strangeness production
- "Exotic" states
- Charm excited states production
- Baryon production

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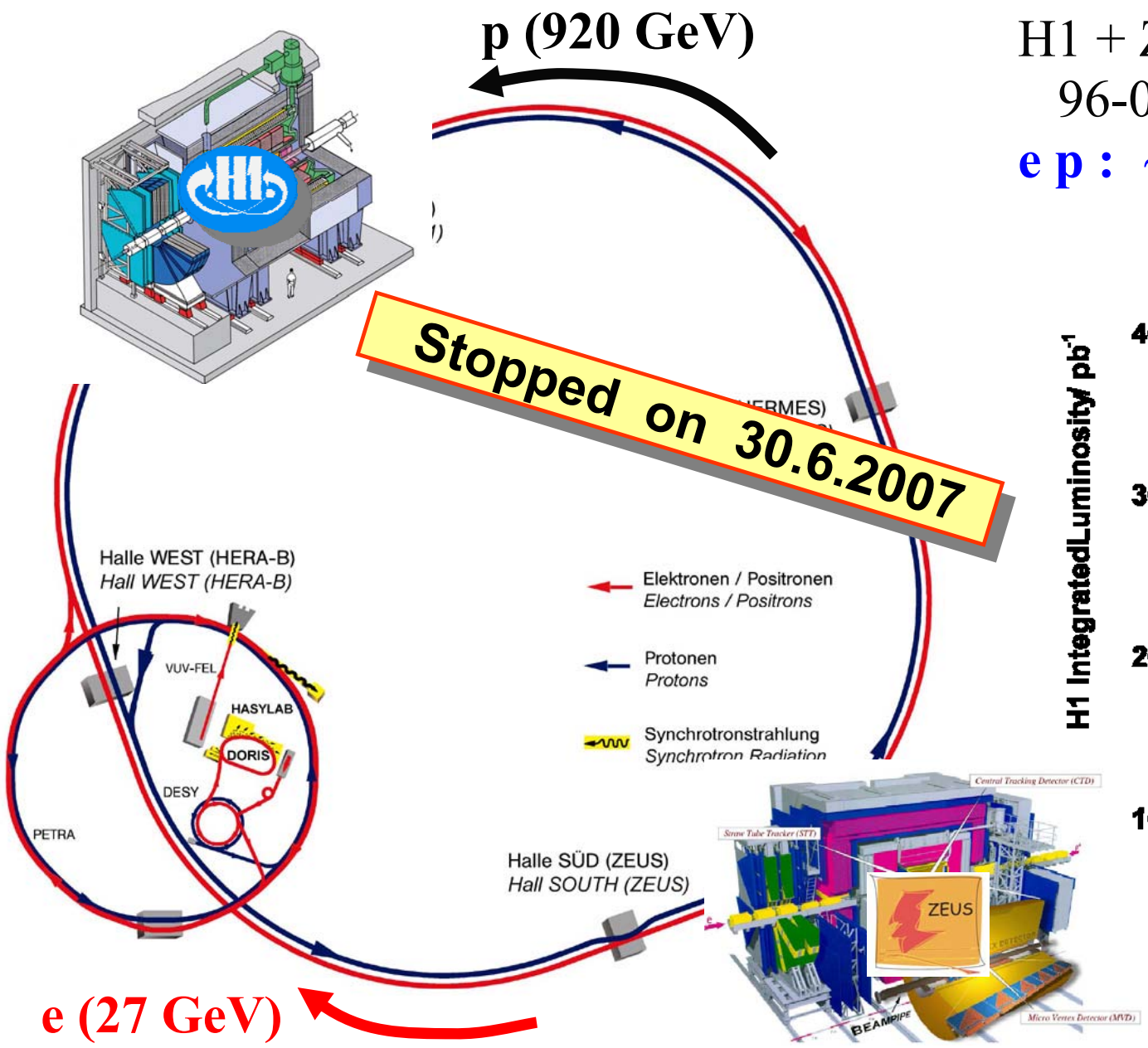
Introduction

Note: various slides marked as “ref”
are included for reference purposes
and are NOT discussed in detail

QCD : Abstracts to cover (14+4 min)

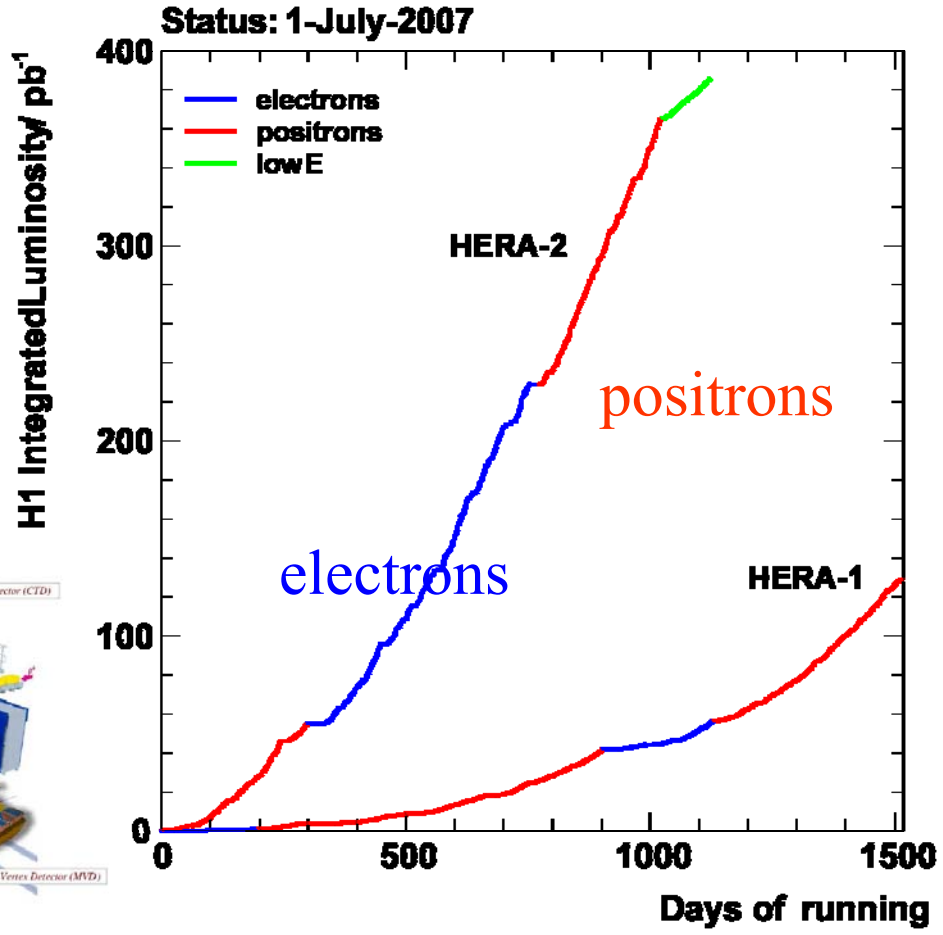
- 120 Measurement of K0s, Lambda, anti-Lambda production with ZEUS at HERA
  ZEUS Collab., DESY-06-226, EPJ C51 (2007) 1
- 123 Measurement of Bose-Einstein correlations of charged and neutral kaons in DIS with ZEUS at HERA :
  ZEUS Collab., DESY-07-069, PL B 652 (2007) 1
- 124 Measurement of (anti)deuteron and (anti)proton production in deep inelastic ep scattering with ZEUS
  ZEUS Collab., DESY 07-070, Nucl. Phys. B 786 (2007) 181,
  H1 Collab., EPJ C36 (2004) 213
- 135 Measurement of inclusive K0sK0s resonance production with ZEUS at HERA
  ZEUS Collab. DESY-08-068
- 243 Measurement of excited charm and charm-strange meson production with ZEUS at HERA
  ZEUS Collab., Contrib. 101 to Int.CHEP-07., DESY-08-093.
- 783 Search for Baryonic Resonances Decaying to Xi pi in Deep-Inelastic Scattering with H1 at HERA
  H1 Collab. Eur.Phys.J.C52:507-514,2007.
- 847 Strangeness Production at low Q2 in Deep-inelastic ep Scattering with H1 at HERA
  H1 Collab. Prelim. DIS 2008, paper in progress;
- 848 Strangeness Production at High Q2 in Deep-inelastic ep Scattering with H1 at HERA
  H1 Collab. expected H1prelim-08-035 (J.Ruiz) Cancelled
- 866 Inclusive (non-diffractive)rho(770), K*(892) and phi(1020) photoproduction with H1 at HERA
  H1 Collab. Prelim. DIS03, (A. Kropivnitskaya) Cancelled
- 867 Inclusive K*+- production at low Q2 with H1 at HERA
  H1 Collab. expected H1prelim-08-032 (D.Sunar)

The HERA Collider (ref)

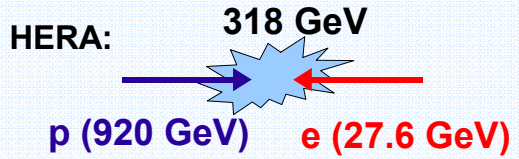


H1 + ZEUS integrated luminosity
96-00 + 03-07 (high energy)

e p : ~ 500 pb^{-1} (each expt.)



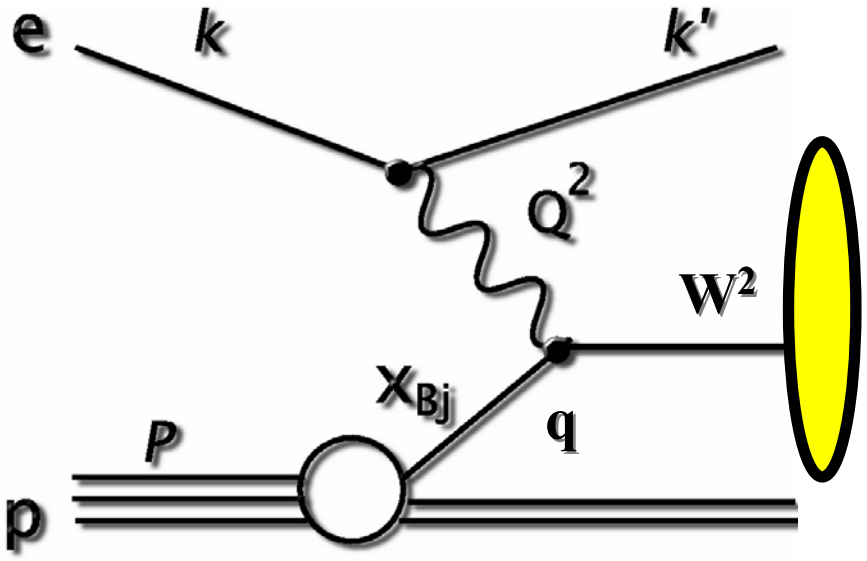
The HERA Kinematics (ref)



e(k) + p(P) → e'(k') + X Lumi ~ 500 pb^{-1} (H1 and ZEUS each)

$$\sigma_{hadron} = \int f(x,\mu)\cdot\hat{\sigma}\cdot D_q^h(x_F,\mu_F)dx$$

D_q^h : Fragmentation of quark q to hadron h



- **Light hadrons**
- **Strange**
- **Charm**
- **Exotics**

$$s = (P+k)^2$$

$$W^2 = (P+q)^2$$

$$Q^2 = -q^2 = -(k-k')^2$$

$$y = \frac{qP}{kP} \cong \frac{W^2+Q^2}{s}$$

$$x_{Bj} = \frac{Q^2}{2qP} \cong \frac{Q^2}{sy}$$

$$x_\gamma = \frac{\sum_{jet1,\,jet2}(E-P_z)}{\sum_{hadrons}(E-P_z)}$$

Relevant Regimes:

$Q^2 < 1$ GeV^2 : Photoproduction (γP): direct and resolved processes (x_γ to separate)

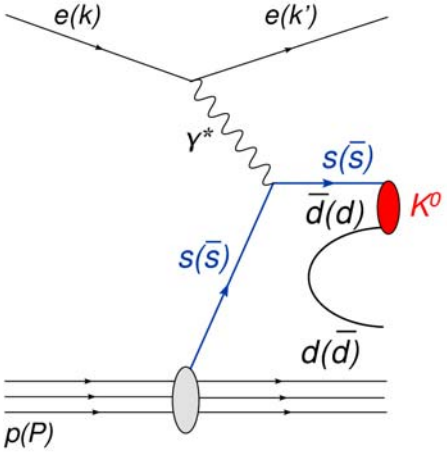
$Q^2 > 1$ GeV^2 : Deep Inelastic Scattering (DIS)

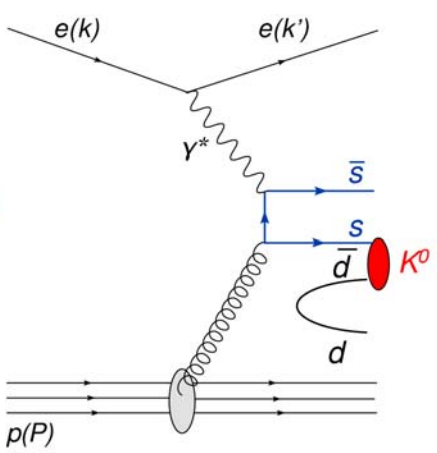
Strangeness Production

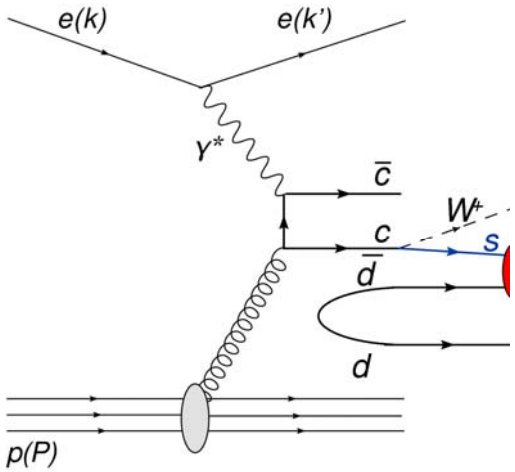
K_s , Λ and K*

Strangeness Production: K_s , K^*, Λ

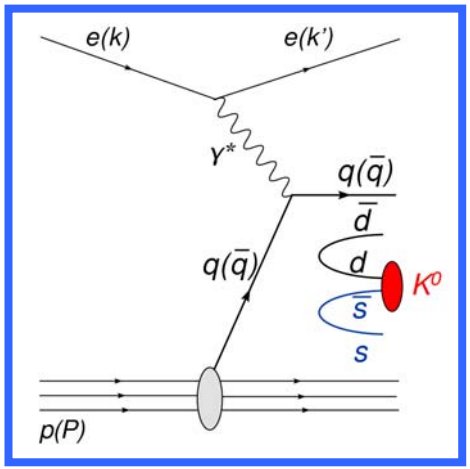
Hard processes : QPM, BGF (s,c), g-splitting (perturbative)





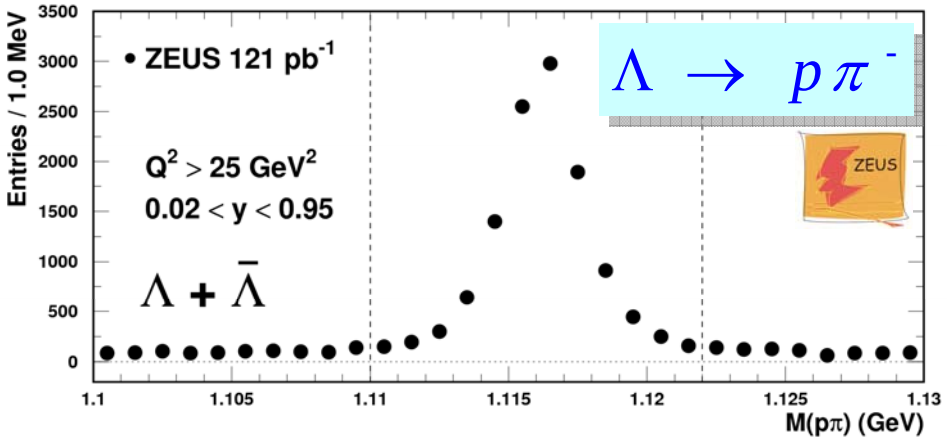


string fragmentation
(non-perturbative)

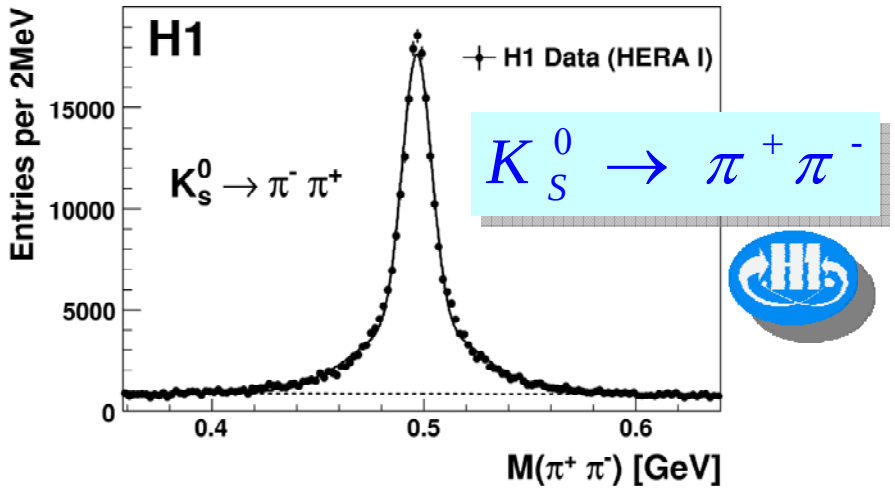


Examples of K^0_s and Λ signals

ZEUS Collab., EPJ C51 (2007) 1



H1 Collab., Prelim 2008



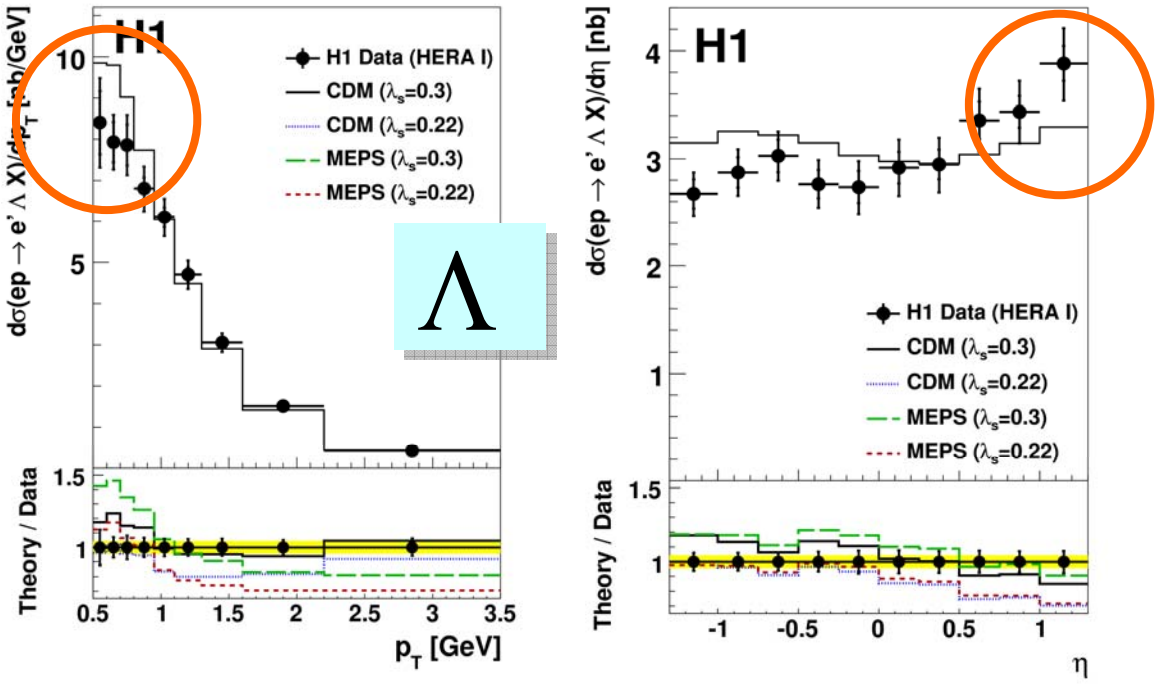
➔ **strangeness production parameters λ_s, λ_{sq}**

K^0_s ,Λ Production in DIS and γp : H1 and ZEUS

Cross sections in p_T^{lab} and η^{lab} , x_γ

DIS: $2<Q^2<100$ GeV^2

H1: Prelim. 2008



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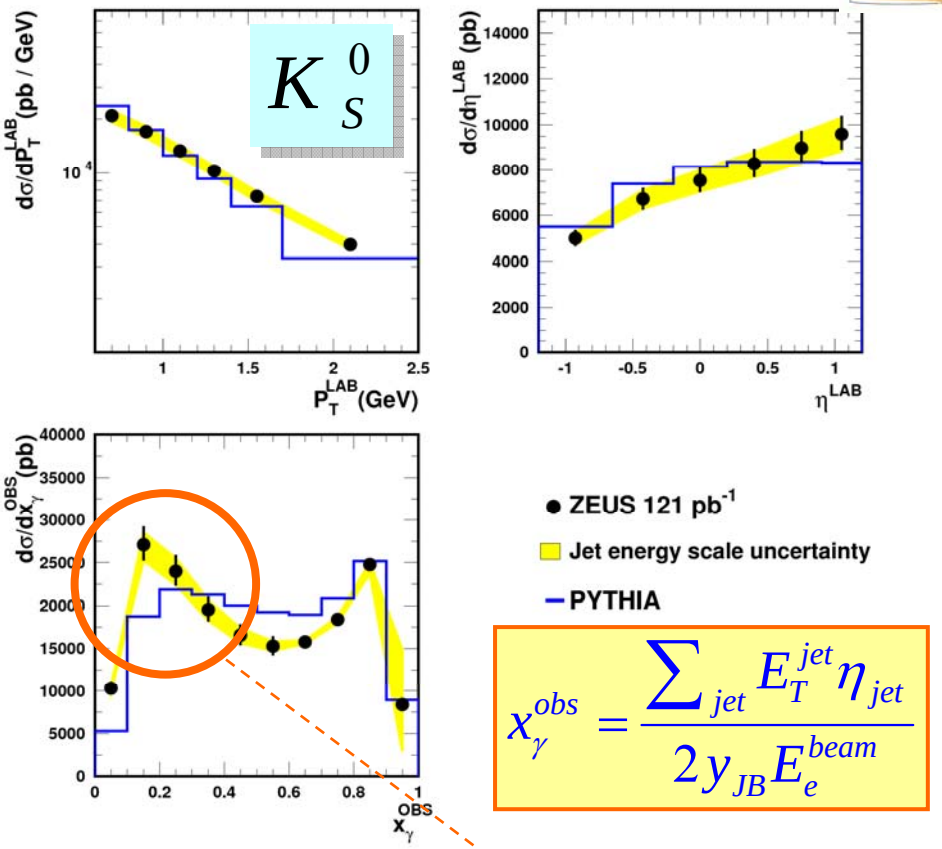
Photoproduction ($Q^2 \approx 0$ GeV^2) :



$$x_\gamma^{obs} = \frac{\sum_{jet} E_T^{jet} \eta_{jet}}{2 y_{JB} E_e^{beam}}$$

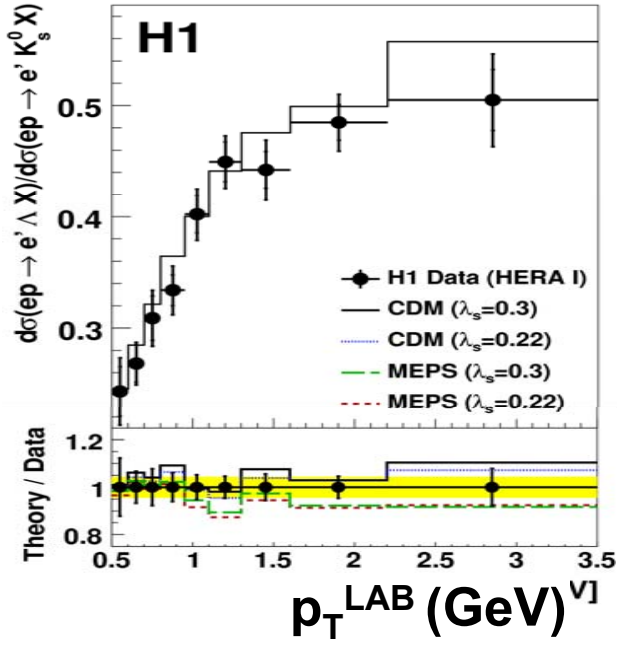
➔ **ARIADNE CDM overall agrees for λ_S=0.3;**
discrepancies in details: e.g. p_T-slope.

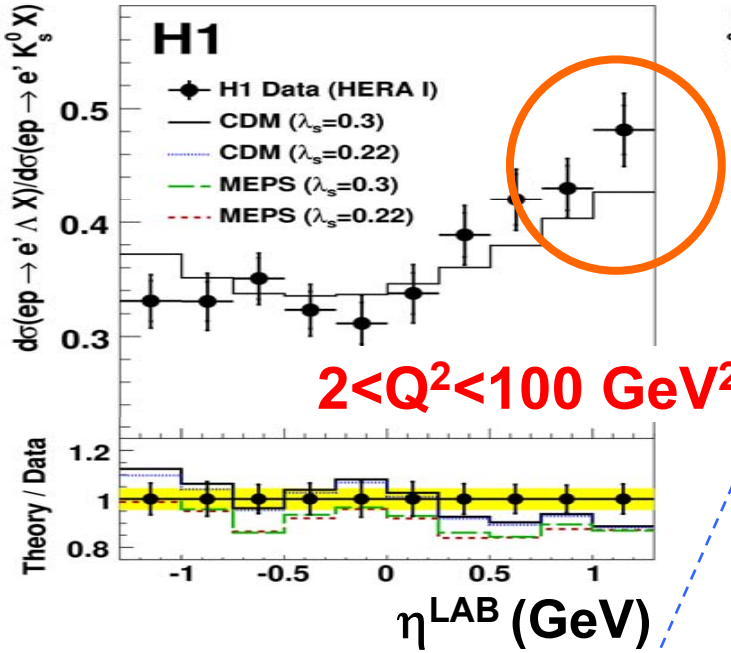
➔ **PYTHIA (normalised to data) describes overall features, except low x_γ^{obs} (resolved)**

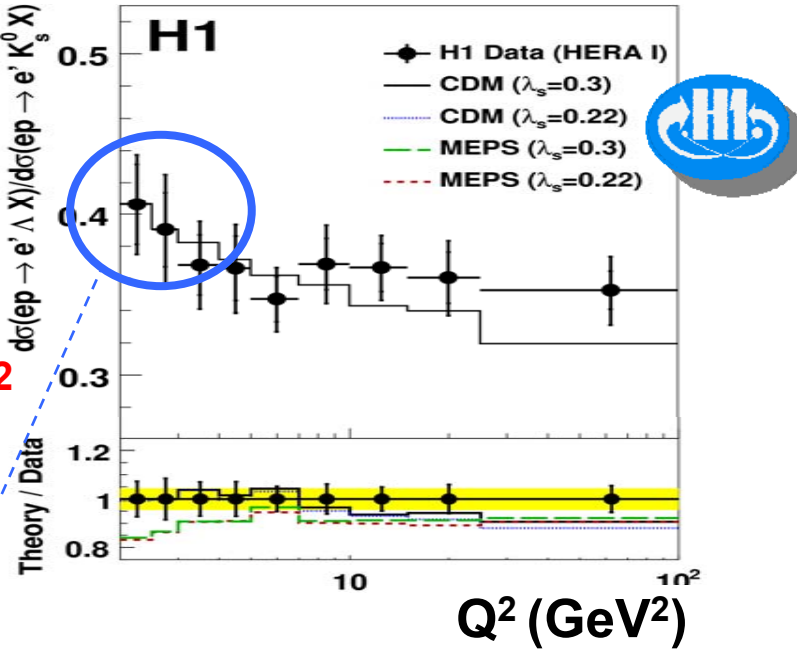
→ Similar, consistent conclusions by H1, ZEUS for K and for Λ production

Strange Baryon Λ to Meson K^0_s Ratio

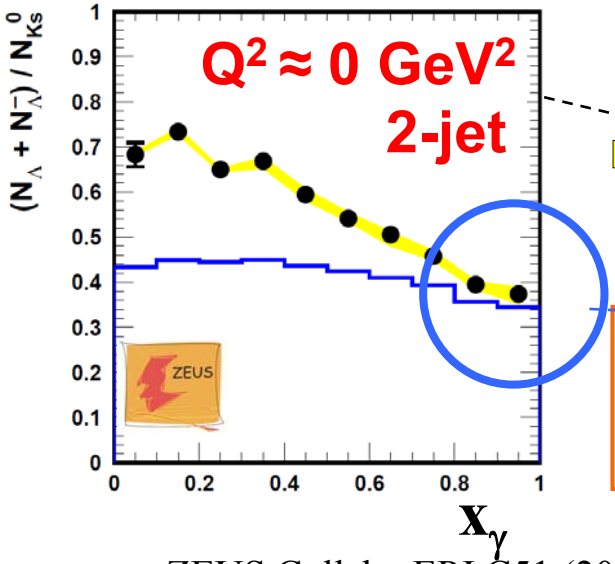
$$\frac{N_\Lambda + N_{\bar{\Lambda}}}{N_{K^0_S}}$$







H1 Collab., Prelim 2008



$$x_\gamma^{obs} = \frac{\sum_{jet} E_T^{jet} \eta_{jet}}{2 y_{JB} E_e^{beam}}$$

- CDM ok at 10% level with λ_s=0.3
- x_γ not described by PYTHIA (incl. MI)
- At $x_\gamma \approx 1$ (direct) : ratio in γp is similar as in DIS at low Q^2, and also similar to measurements in e^+e^-

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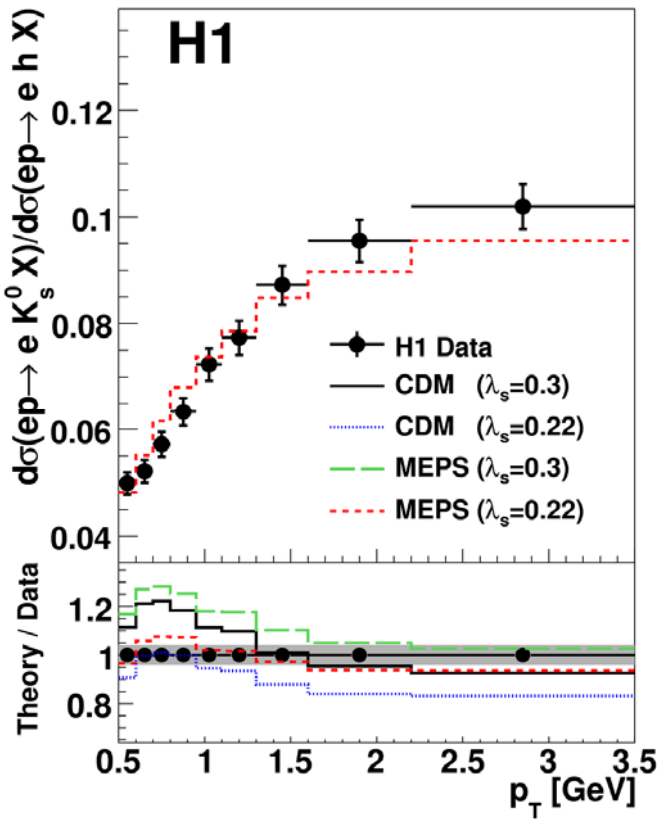
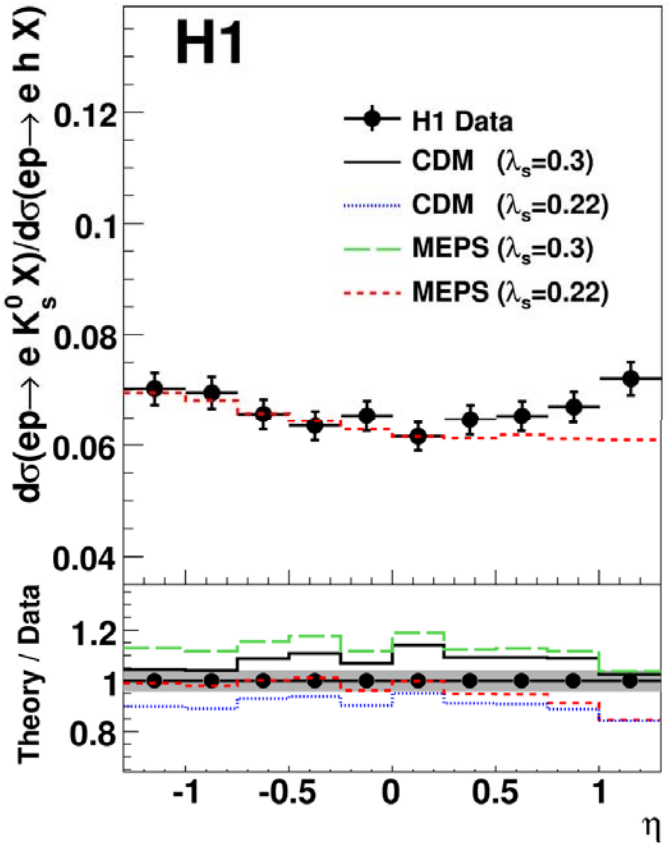
Strange K^0_s to Light Hadrons h Ratio





h= all charged particles

$$\frac{N_{K^0_S}}{N_{charged}}$$

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

H1: prelim. ICHEP08

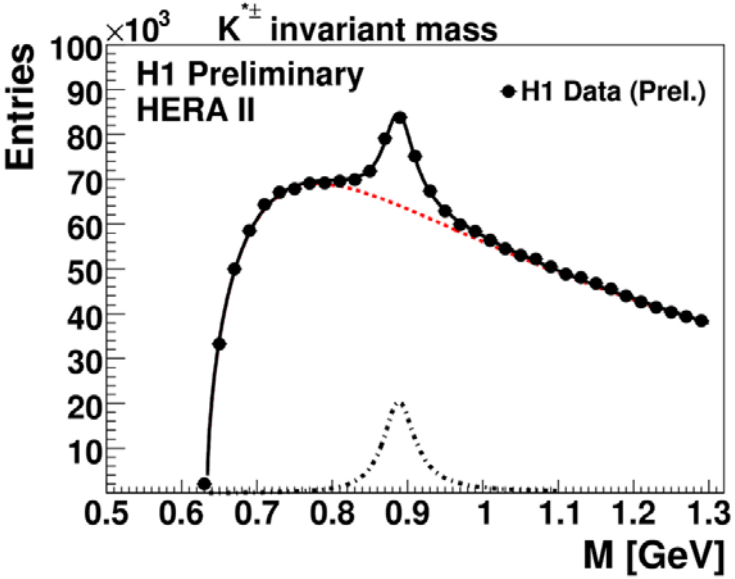
- ➔ **K/hadrons :** overall described by CMD and MEPS, favour smaller λ_s=0.22 !
- **K_S, Λ, Λ/ K_S** : better described by CMD with larger λ_s=0.3 (ALEPH) and Pythia (in γp)
- **Λ : NO** asymmetry observed between between Λ and anti-Λ (H1 and ZEUS)
- **General:** H1 and ZEUS consistent; overall features described, details NOT; single λ_S is NOT sufficient; need overall fit to extract λ_S and λ_{qq} ,λ_{qs}

K*(892) Production in DIS

$5<Q^2<100$ GeV^2 , 301 pb^{-1}

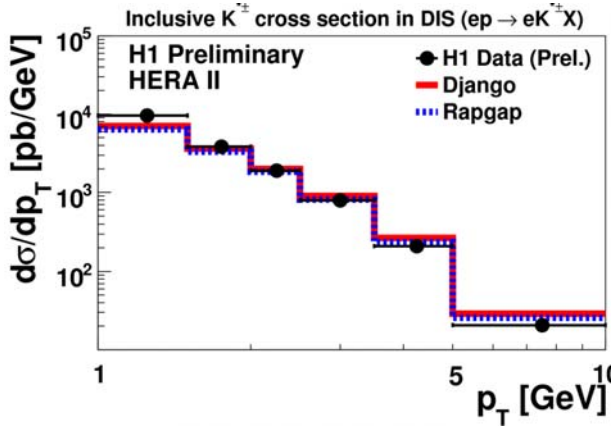
$$K^{*\pm} \rightarrow K^0_S \pi^{\pm}$$

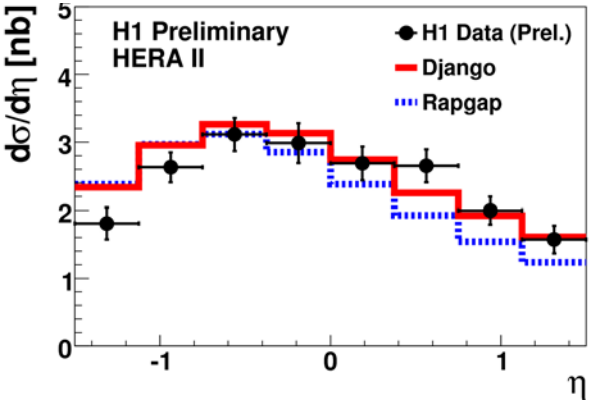
K* : fitted with relativ. BW

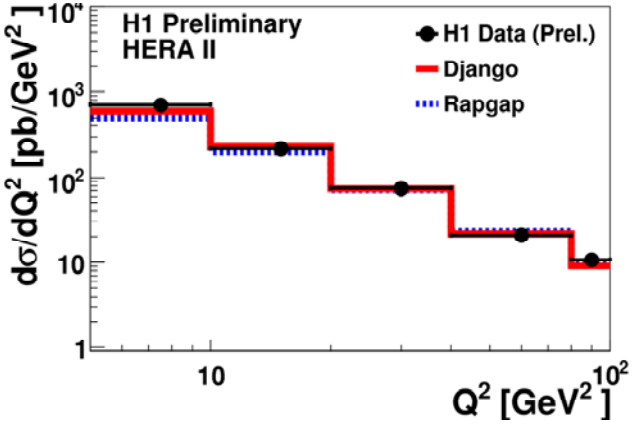


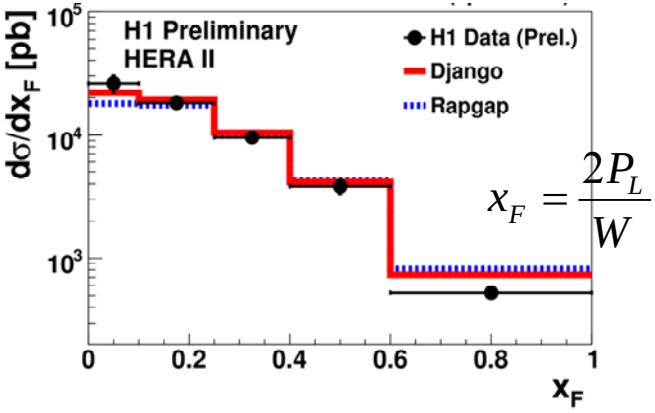
H1 Collab., Prelim 2008

Inclusive cross sections









$$x_F = \frac{2P_L}{W}$$

- **K* cross sections measured first time at HERA :** overall features described by Django (CDM) and RAPGAP (MEPS), details NOT (eg. eta shape)
- Conclusions consistent with K_S , Λ data

Bose Einstein Correlations in Kaons

Bose-Einstein Correlations for $K^{\pm}K^{\pm}$, K_SK_S (ref)

Measure size and shape of particle emitting source.
Identical bosons emission enhanced close in phase space.

Distance in phase space characterized by:

r = source size of particle emission

Q_{12} = distance in 4-momentum space

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

Correlation function $R(Q_{12})$, defined by two-particle density functions $P(Q_{12})$:

$$R(Q_{12}) = P(Q_{12}) \,/\, P_{noBEC}(Q_{12})$$

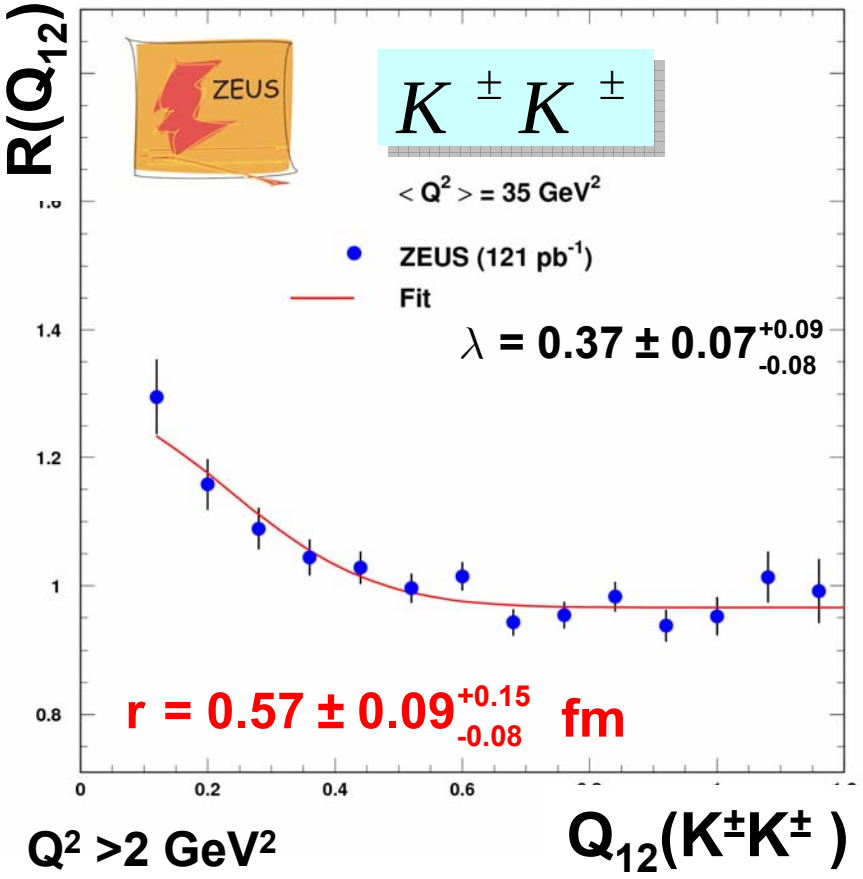
Static Gaussian source of strength λ:

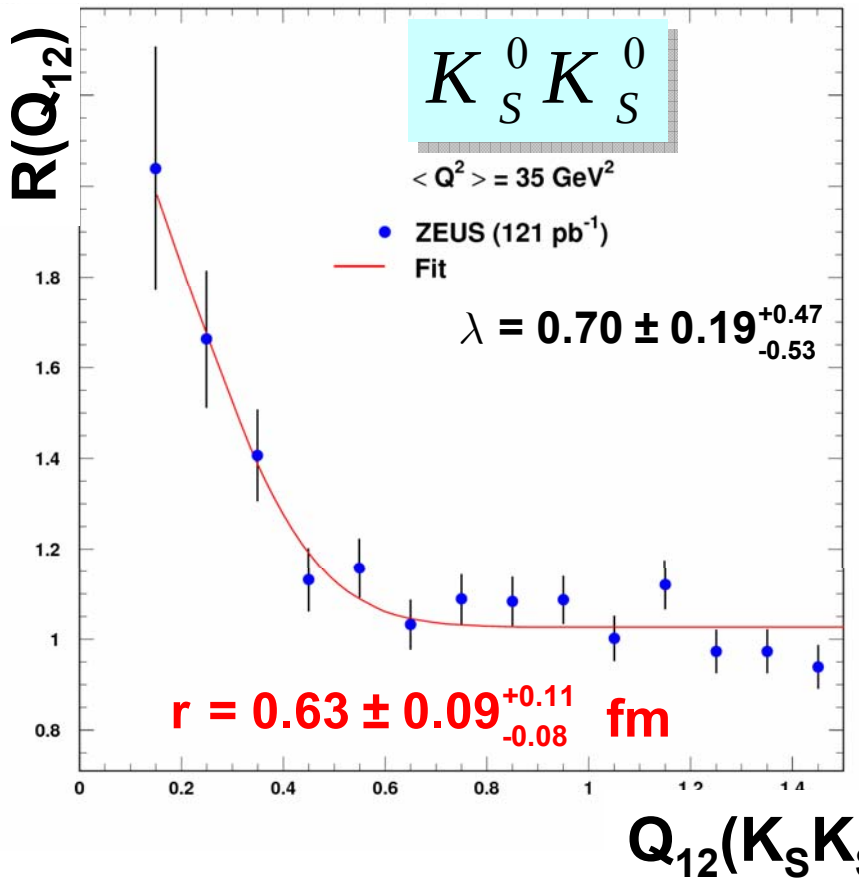
$$R_{Gaus}(Q_{12}) = 1 + \lambda \exp(-r^2 Q^2_{12})$$

Reduce model sensitivity via double ratios R:

$$R(Q_{12}) = \frac{P(Q_{12})^{data}}{P_{mix}(Q_{12})^{data}} \Big/ \frac{P(Q_{12})^{MC,noBEC}}{P_{mix}(Q_{12})^{MC,noBEC}}$$

Bose-Einstein Correlations for $K^{\pm}K^{\pm}$, $K_S K_S$





Source size r and distance Q_{12} in 4-momentum space

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

λ =source strength

$Q^2 > 2$ GeV^2

121 pb^{-1}

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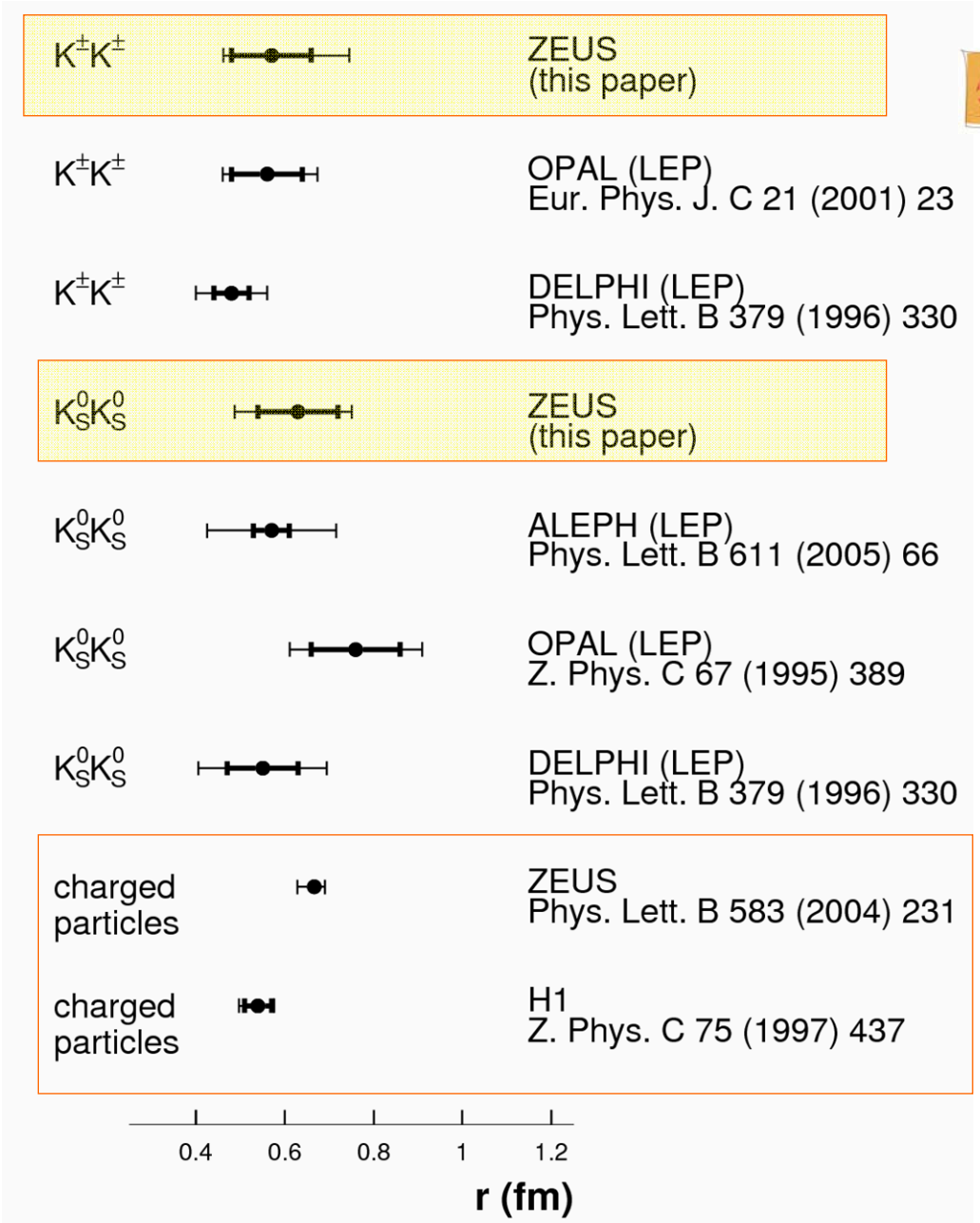
- **Bose-Einstein correlations clearly established for $K^{\pm}K^{\pm}$ pairs**
- **K_s K_s inconclusive, $f_0(980) \rightarrow K_s$ K_s background → large systematics**
- **Source radius "r" found similar**

BEC: Source Radius *r*



***r* values found consistent in :**

- ep (DIS) vs. e^+e^-
- $K^{\pm}K^{\pm}$ and $K_s K_s$ (marginal)
- Kaons vs. charged particles

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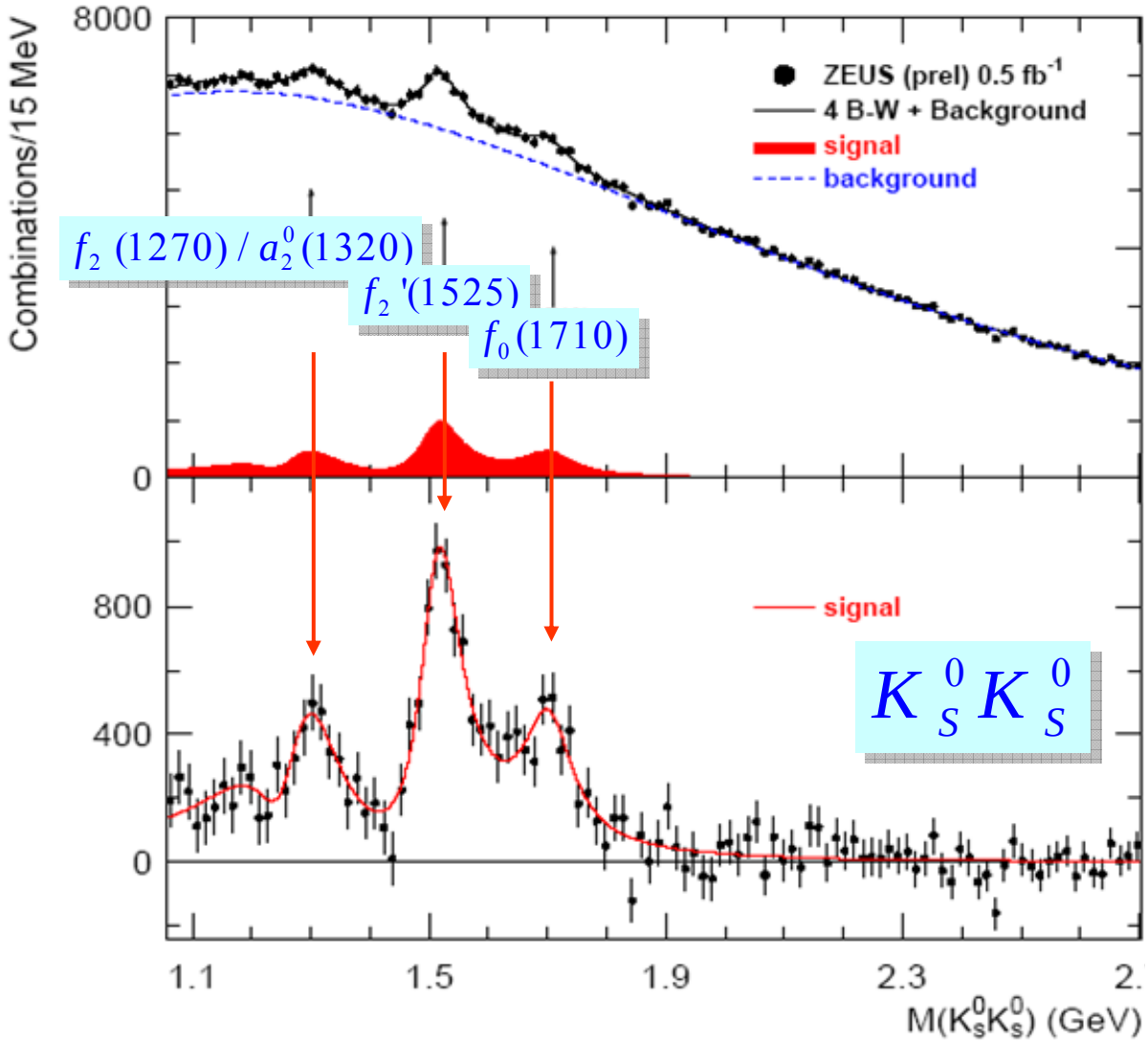
Glueball Candidates in $K^0_S K^0_S$ Mass Spectra ?

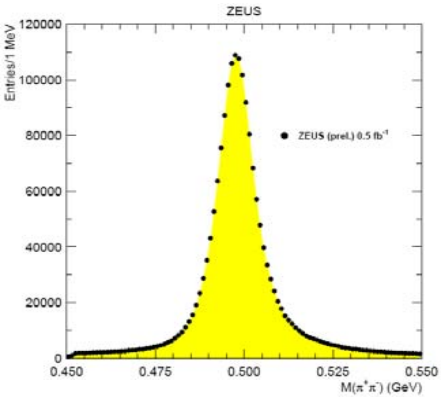
$K^0_S K^0_S$: Glueball Candidate

- $K^0_S K^0_S$ spectrum (672418 comb) : HERA-I+II data ~500 pb^{-1} ; all Q^2



- **lightest glueball candidate expected**:
  $J^{PC} = 0^{++}$; M=1730 ± 100 MeV
  eg. seen by **WA102, L3 :** $f_0(1710)$

$K^0_S \to \pi\pi$



ZEUS observes 3 structures:

Interference fit of spectra with multiple relativ. BWs;
and determine mass and widths

ZEUS Collab., DESY 08-068

Structures in $K^0_S K^0_S$ Resonances

in MeV	$f_2'(1525)$	$f_0(1710)$
mass	$1512 \pm 3^{+1.4}_{-0.5}$	$1701 \pm 5^{+9}_{-2}$
width	$83 \pm 9^{+5}_{-4}$	$100 \pm 24^{+7}_{-22}$
Particle Data Group 2007 Values		
mass	1525 ± 5	1724 ± 7
width	73^{+6}_{-5}	137 ± 8

- Evidence for $f'_2(1525)$ and $f_0(1710)$ [at 5 sigma]
- Masses of $f_2'(1525)$ and $f_0(1710)$ found bit low, but widths consistent with PDG
- $f_0(1710)$ is consistent with $J^{PC}=0^{++}$ glueball candidate

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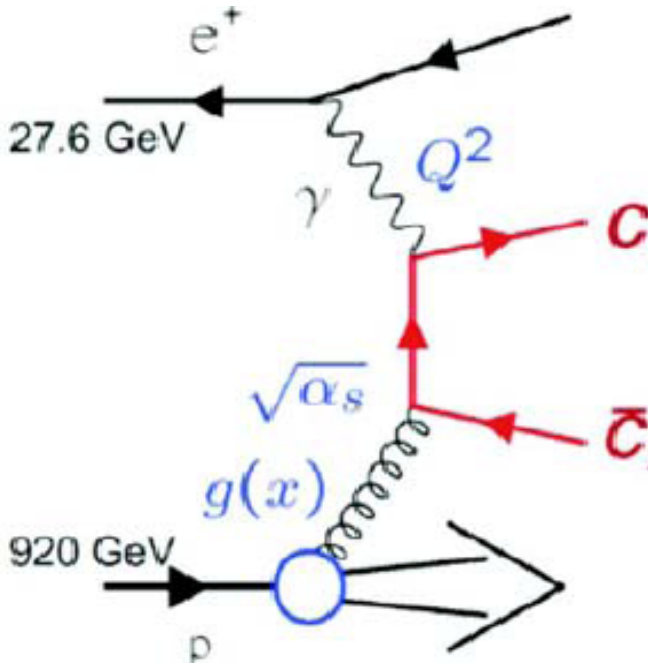
Charmed Particle Production

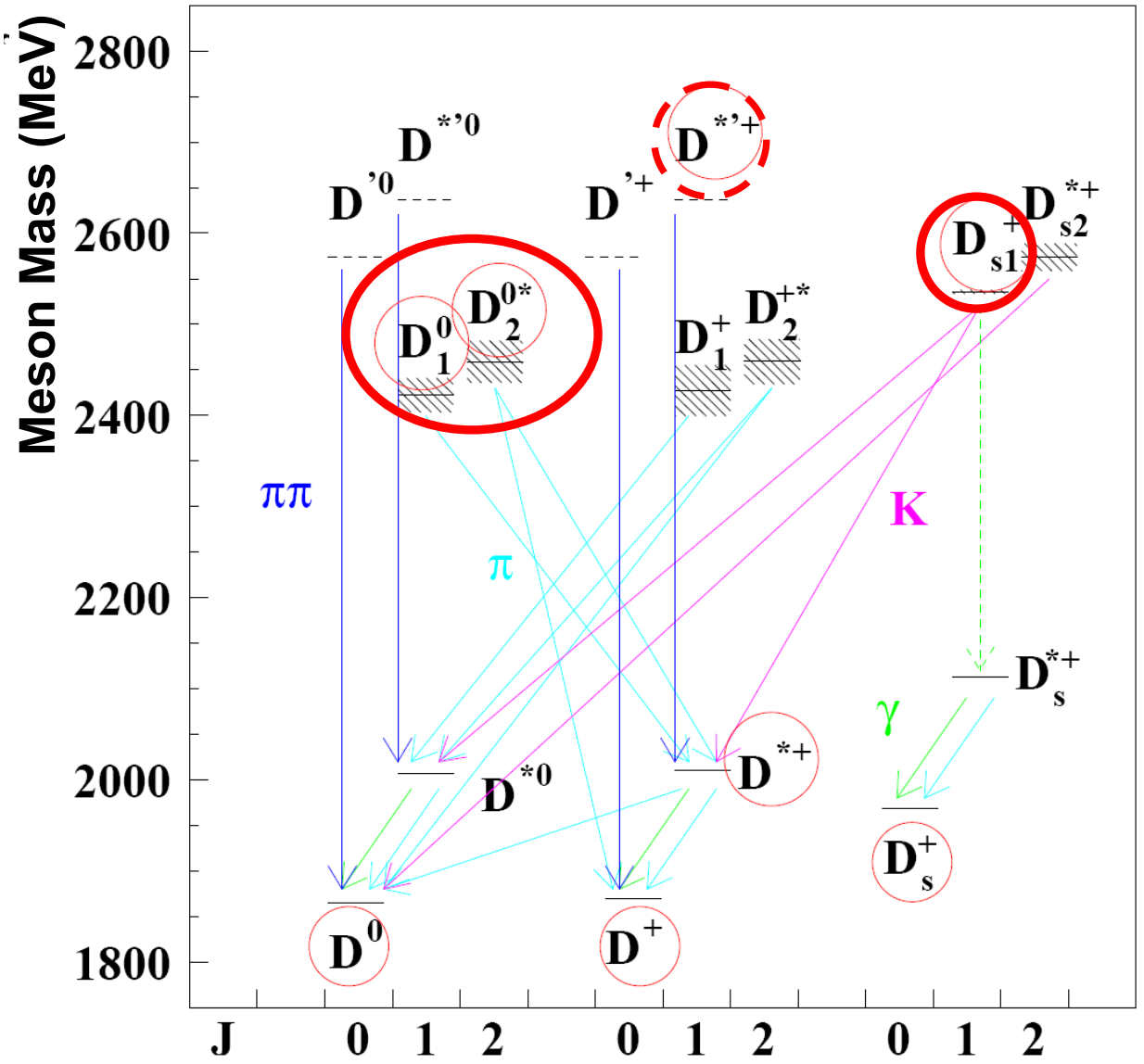
Dominated by photon-gluon fusion



Excited Charmed Mesons

- Measure orbitally excited D-mesons (doublets) through decays :
  - $D_1(2420)^0 \rightarrow D^{*+} \pi^-$
  - $D_2^*(2460)^0 \rightarrow D^{*+} \pi^-$, $D^+ \pi^-$

  and
  - $D_{S1}(2536)^+ \rightarrow D^{*0} K^+$, $D^{*+} K_S^0$
- Search for radially excited state $D^{*'+}(2640) \rightarrow D^{*+} \pi^- \pi^+$



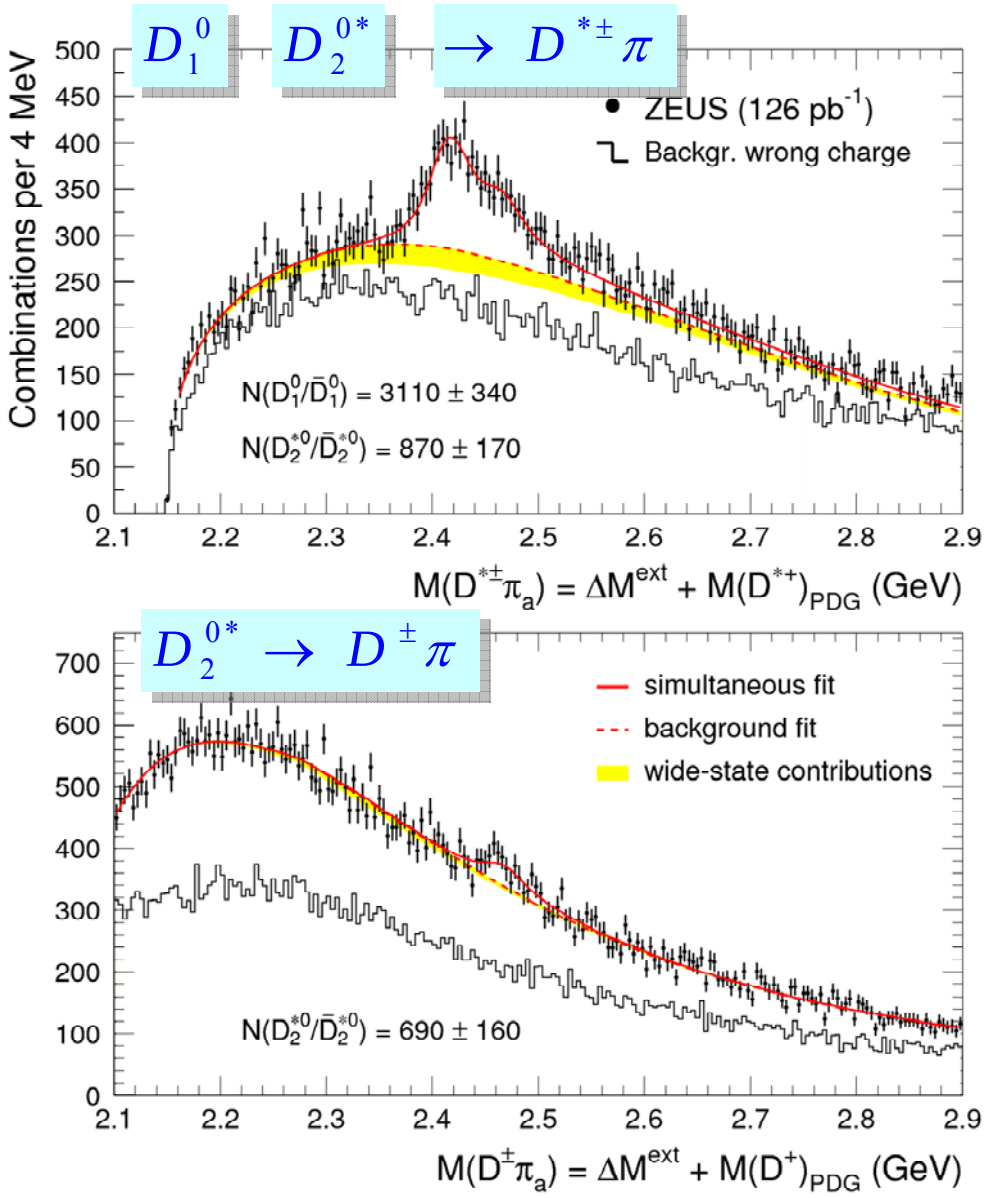
Excited Charmed Mesons

- **Orbitally excited P-wave mesons:**

  D^0_1, $D^{*0}_2 \rightarrow D^{*+}\pi^-$ and $D^{*0}_2 \rightarrow D^{\pm}\pi$

- **ZEUS observed :**
  $N(D^0_1[2420]) = 3110 \pm 340$ events
  $N(D^{*0}_2[2460]) = 1560 \pm 233$ events

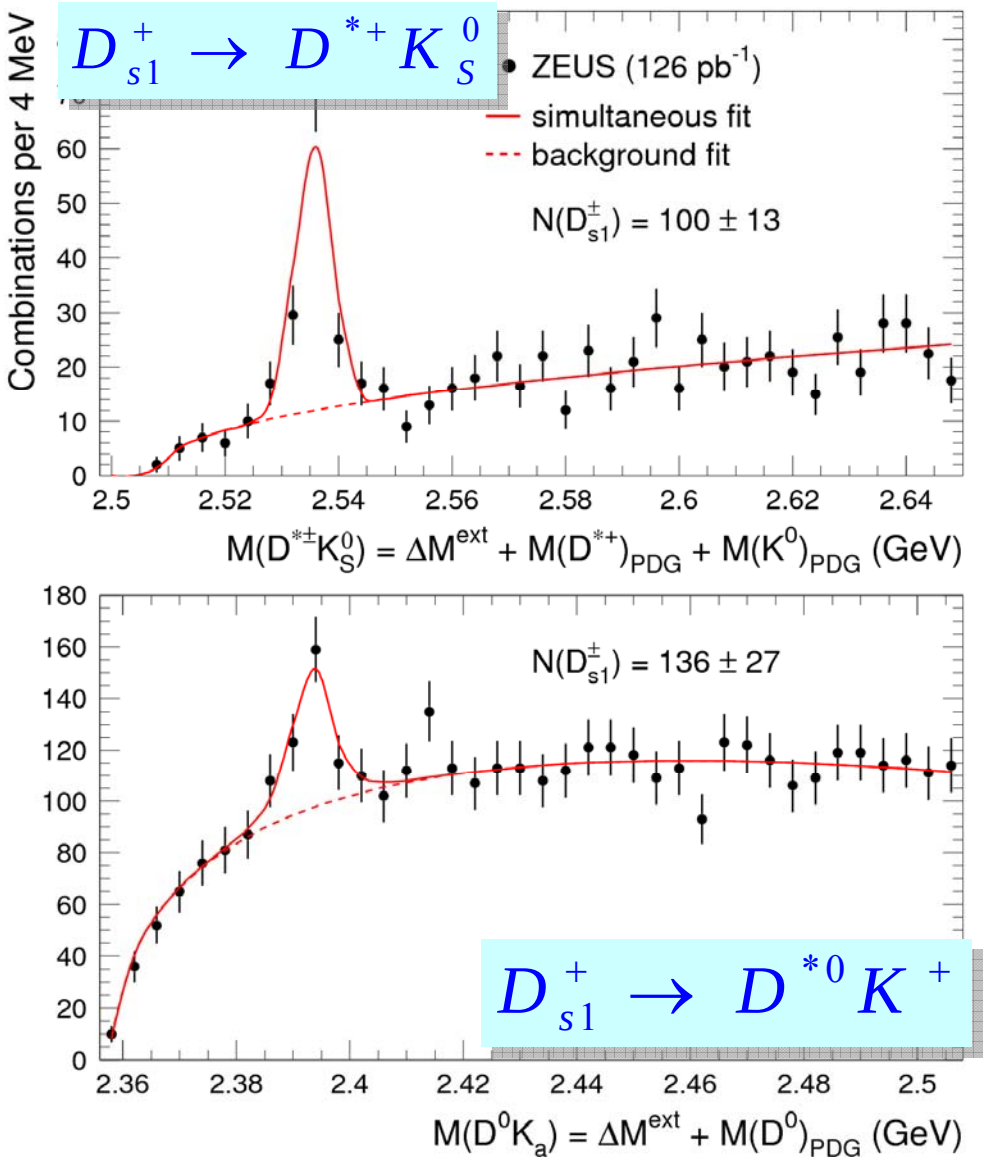
- **and determined**
  - **masses,**
  - **rel. branching ratios,**
  - **fragmentation fractions,**
  - **helicity distributions, and**
  - **width of D^0_1**



ZEUS DESY-08-093.

Charmed Strange Particles

- **Observed orbitally excited (cs) mesons** $D^+_{s1}(2536)$



ZEUS measured:

100 +- 13 events in $D^+_{s1} \to D^{*+} K^0_S$

136 +- 27 events in $D^+_{s1} \to D^0 K^+$

Fits for helicity parameter between K^0_S and π_s in D* rf $dN \sim (1+h\cos^2\theta)$ gives

$$h(D^+_{s1}) = -0.74^{+0.23}_{-0.17}(stat)^{+0.06}_{-0.05}(sys)$$

h≠0 suggests mixture of two 1^+ states, eg. D+S waves to the $D_{s1}(2536)^+ \to D^{*+}K^0_S$

→ this is consistent

*** with Belle value and CLEO range**

*** not with h=3 for pure D 1^+ state**

*** not really with h=0, for pure S 1^+**

ZEUS DESY-08-093.

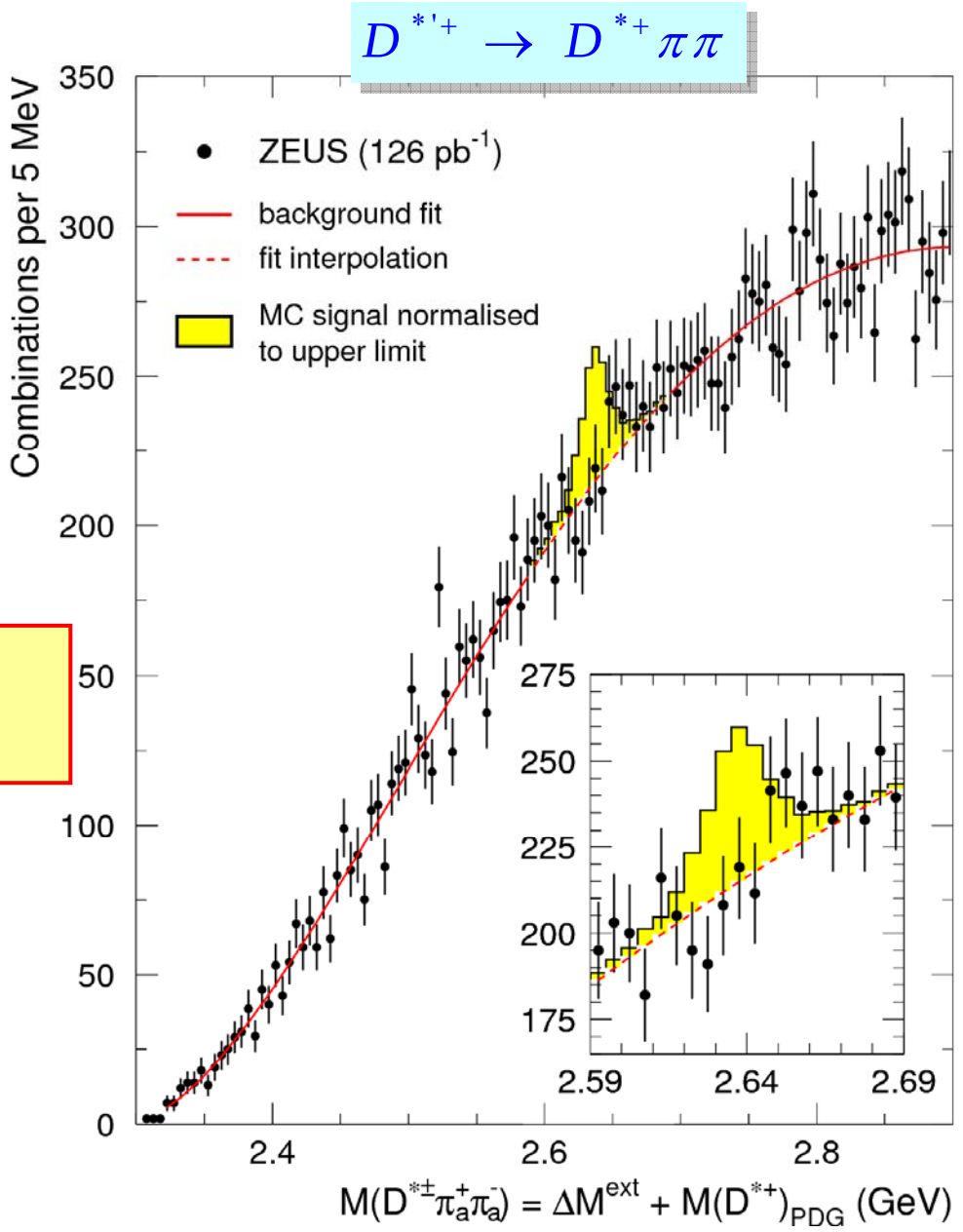
Excited Charmed Mesons

- NO signal seen in search for
  radially excited
  $D^{*'+}(2640) \rightarrow D^{*+} \pi^- \pi^+$
  → best upper limit on f*Br

  in 2.59 < M < 2.69 GeV

$f(c \rightarrow D^{*'+}) * B(D^{*'+} \rightarrow D^{*} \pi\pi)$

< 0.4% (95% CL)



ZEUS DESY-08-093.

Excited Charm (ref)

ZEUS DESY-08-093.

	Mass (Mev)
$D_1(2420)^0$	$2420.5 \pm 2.1(stat) \pm 0.9(syst) \pm .2(PDG)$
$D_2^*(2460)^0$	$2469.1 \pm 3.7(stat)^{+1.2}_{-1.3}(syst) \pm .2(PDG)$
$D_{S1}(2536)^+$	$2535.57^{+0.44}_{-0.41}(stat) \pm 0.1(syst) \pm 0.17(PDG)$

consistent with PDG values

	Fragmentation fraction%
f(c→ $D_1(2420)^0$)	$3.5 \pm 0.4^{+0.4}_{-0.6}$
f(c→ $D_2^*(2460)^0$)	$3.8 \pm 0.7^{+0.5}_{-0.6}$
f(c→ $D_{S1}(2536)^+$)	$1.11 \pm 0.16^{+0.08}_{-0.10}$
f(c→ D*'+) x Br	<0.4% at 95% C.L.

consistent with e^+e^- values

best limit to date

- **Width:** $\Gamma(D_1^0) = 53.2 \pm 7.2(stat)^{+3.3}_{-4.9}(syst)$ — larger than world average
- **Ratios:**

$$BR(D_2^{*0} \to D^+\pi^-/D^{*+}\pi^-) = 2.8 \pm 0.8(stat)^{+0.5}_{-0.6}(syst)$$

$$BR(D_{S1}^+ \to D^{*0}\,K^+ / D^{*+}\,K^0) = 2.3 \pm 0.6(stat) \pm 0.3(syst)$$

consistent with PDG values

- **Helicity par:**

$$h(D_1^0) = +5.9^{+3.0}_{-1.7}(stat)^{+2.4}_{-1.0}(sys)$$

consistent with pure D-wave (h=3)

$$h(D_{s1}^+) = -0.74^{+0.23}_{-0.17}(stat)^{+0.06}_{-0.05}(sys)$$

inconsistent with pure S-wave (h=0)

Baryon Production

$ep \to \bar{p}, p, \bar{d}, d$ - Baryon Production

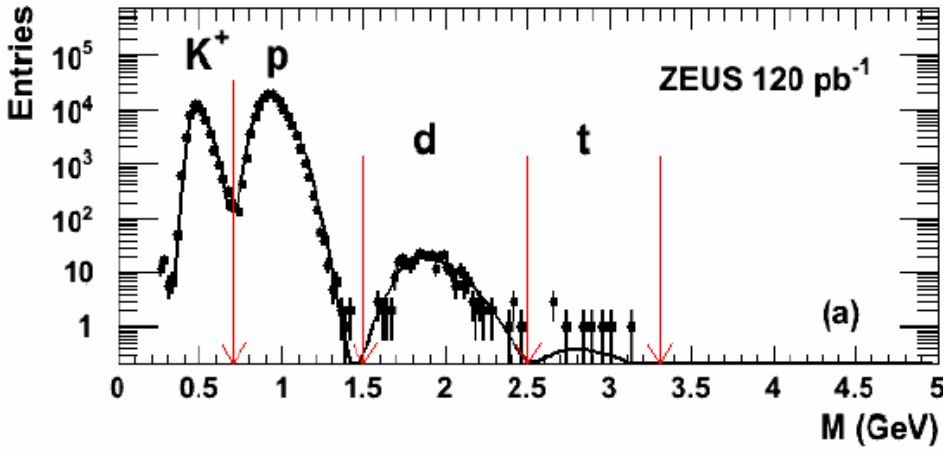
ZEUS Collab., DESY 07-070 (120 pb^{-1})

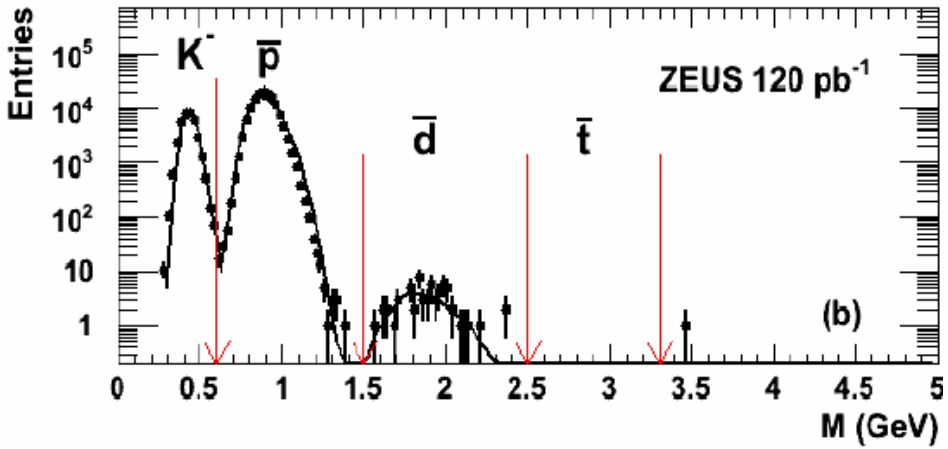
- To better understand production, and test coalescence model prediction:

$$d\sigma_d \propto (d\sigma_p \cdot d\sigma_n) \propto (d\sigma_p)^2$$

- Expect coalescence parameter B2 (nucleon overlap) to be equal for particle and antiparticle, and
- Thus expect

$$\bar{d} / d = (\bar{p} / p)^2$$





- HERA data:
  ZEUS 120 pb^{-1}: 65 anti-d in DIS
  H1 6 pb^{-1}: 45 anti-d in photoproduction

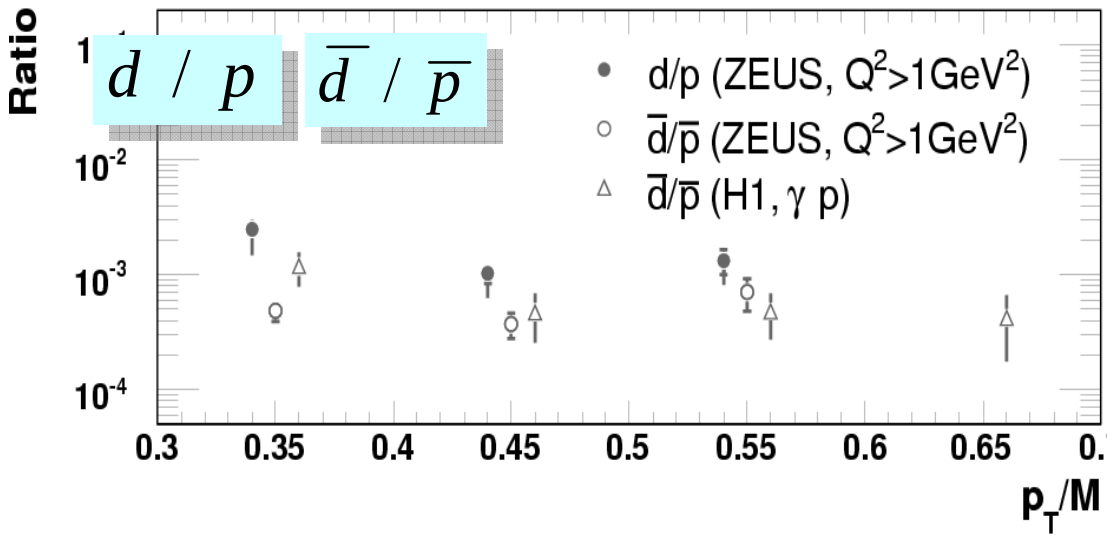
Good separation, based on p and dE/dx

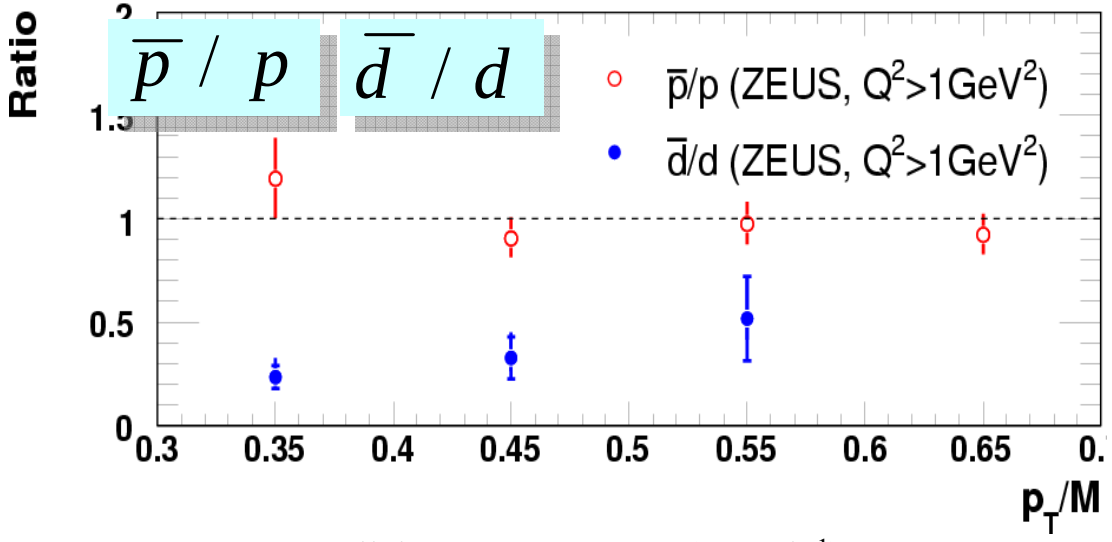
$ep \to \bar{p}, p, \bar{d}, d$ - Baryon Production

Results:

- **Proton and Anti-p yields** are ~ 1000 x larger than d and anti-d
- **anti-d / anti-p ratio :**
  ZEUS and H1 are consistent
- **anti-p/p ratio is consistent with unity;**
  thus expect (anti-d / d) also ~ 1
  ➔ **NOT seen**

  But: no sensitivity to model predictions at the necessary <10% level
- **Q: are there more d than anti-d ?**
  - Is the coalescence parameter different for particle and anti-particles?
  ➔ need confirmation





ZEUS Collab., DESY 07-070 (120 pb^{-1})

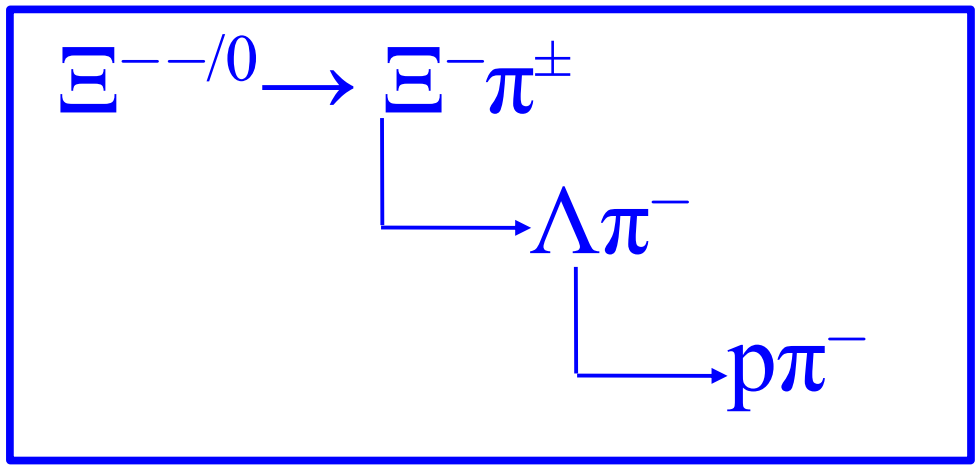
H1 Collab., EPJ C36 (2004) 213 (5.5 pb^{-1})

Baryonic States decaying to $\Xi\pi$

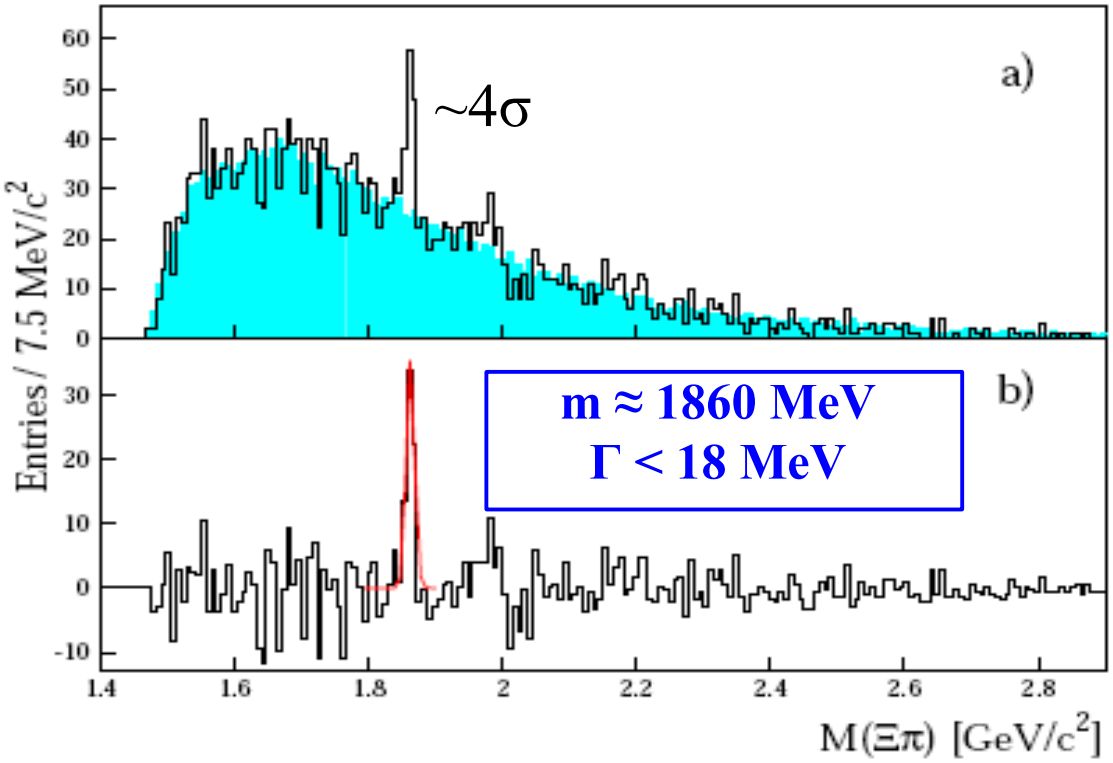
Pentaquark candidate ?

An S=-2 State $\Xi^{--/0} \rightarrow \Xi\pi$?

Remember the NA49 "4σ hint" at mass 1862 MeV ...



NA49 Collab., PRL 92 (2004)



➔ **H1+ZEUS** searched for doubly charged and neutral states Ξ^{--}_{5q} and Ξ^{0}_{5q} produced in DIS

H1:EPJ C52 (2007) 507

ZEUS: PL B610 (2005)

Not seen by any other experiment
(WA89, ALEPH, BES, FOCUS, COMPASS, CDF,...)

Baryonic States decaying → Ξπ in DIS

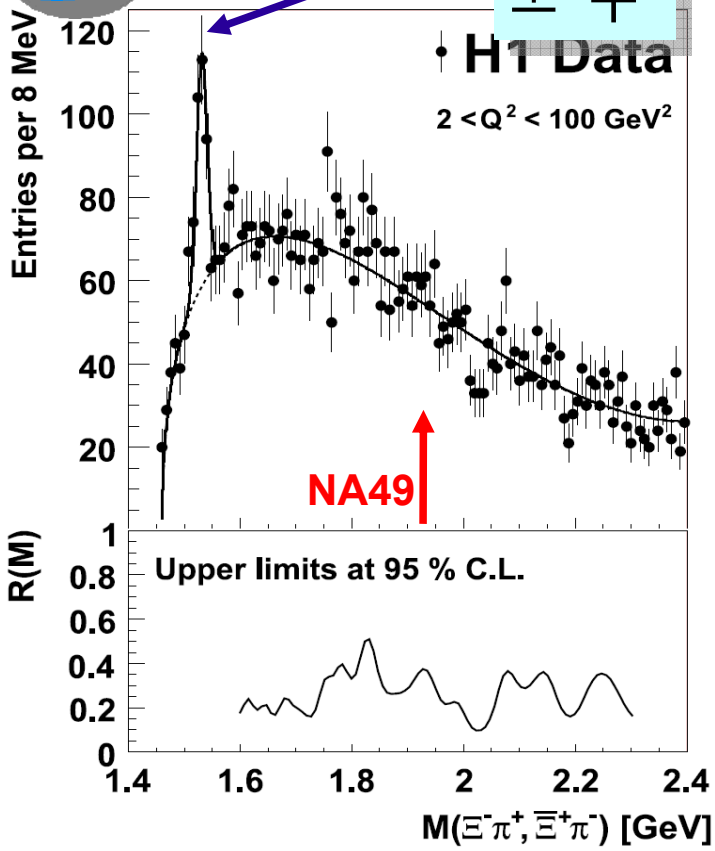
All upper limits relative to $\Xi^0(1530)$

H1:EPJ C52 (2007) 507

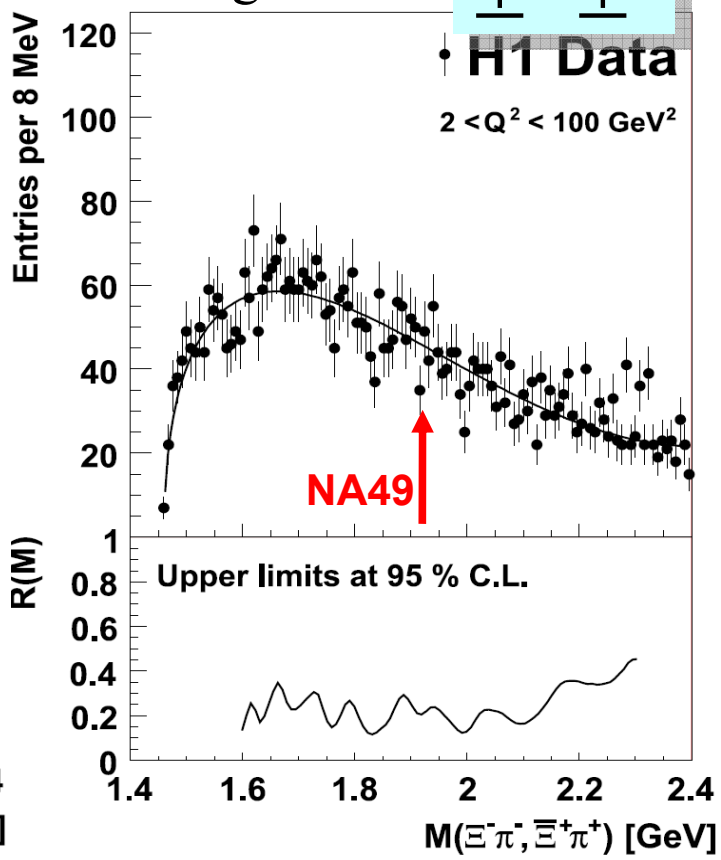
ZEUS: PL B610 (2005)

$\Xi\ \pi$

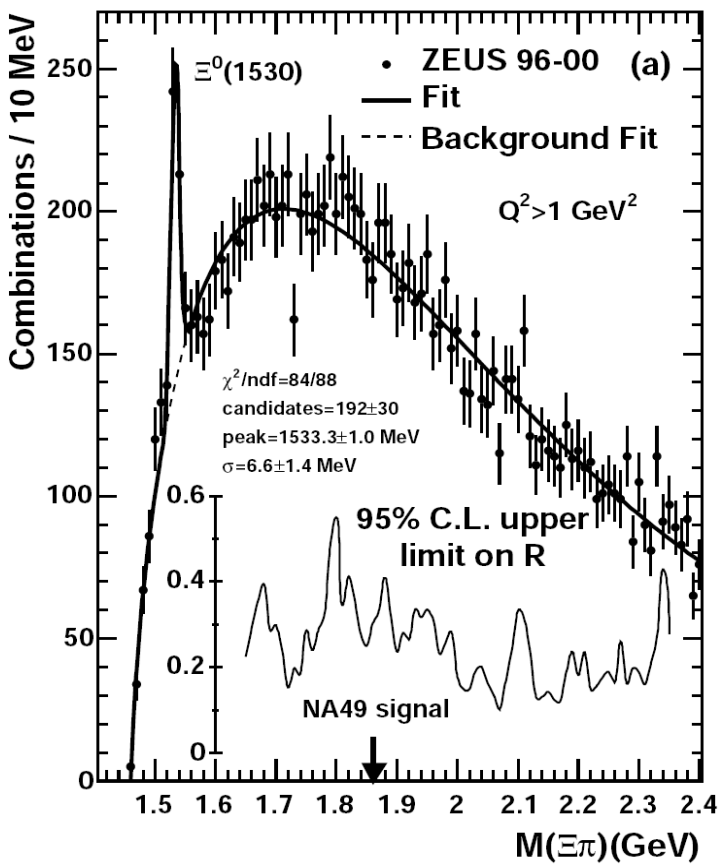
neutral comb $\pm\ \mp$



charged comb $\pm\ \pm$



all comb.



- → **NA49** observation at 1862 MeV not confirmed
- → **H1+ZEUS:** Search for Ξ^{--}_{5q} and Ξ^{0}_{5q} decaying to Ξπ

No evidence seen for any exotic 5q state in Ξπ

Summary

- **Strange particle production**
  - K_S, Λ , Λ/K_S ratios: Zeus and H1 data agree ☺
    CDM describes overall features well with λ_S=0.3 (ALEPH tune); differences seen in details
  - K* production : supports K_S, Λ messages
  - $K^{\pm}K^{\pm}$ Bose-Einstein Correlations clearly observed;
    source radius r~0.6 consistent with e^+e^- data, and charged particles

- **Glueball candidate in K_sK_s resonance** ☺
  - Clear evidence for $f'_2(1525)$ and $f_0(1710)$ resonance state :
  - interference fit yields (m,Γ), consistent with PDG
- **Charmed particle production:** ☺
  - orbital excited D-mesons measured (D^0_1, D^{*0}_2 , D^+_{S1}):
    masses in agreement with PDG; radial excited state $D^{*'+}$ not seen.

- **Baryon production:**
  - d (+anti-d) production ~1/1000 of p (+anti-p) production; p/anti-p is ~ unity.
  - more d than anti-d ? is coalescence parameter not universal ?

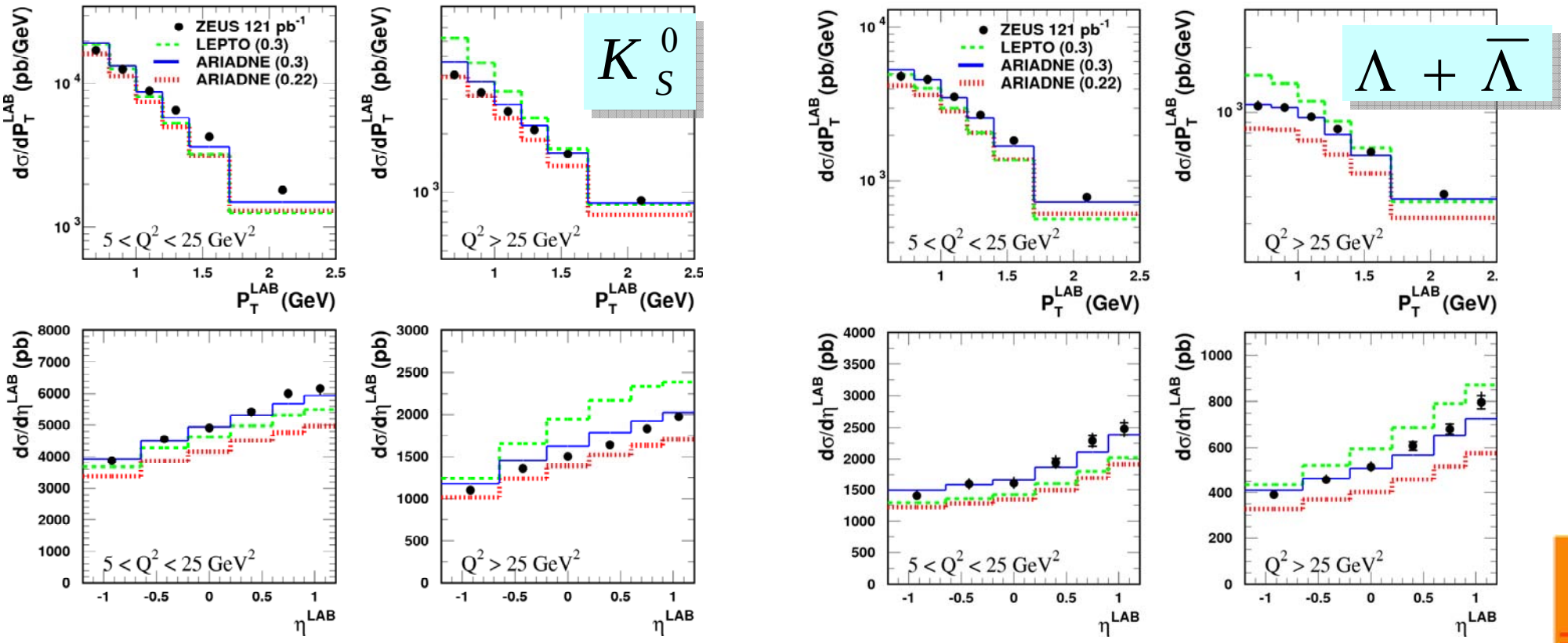
➔ **HERA provides a wealth of complementary information …**

Backup slides

K^0_s and Λ Production in DIS

K^0_s and Λ production cross sections in p_T^{lab} and η^{lab} (121 pb^{-1})

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

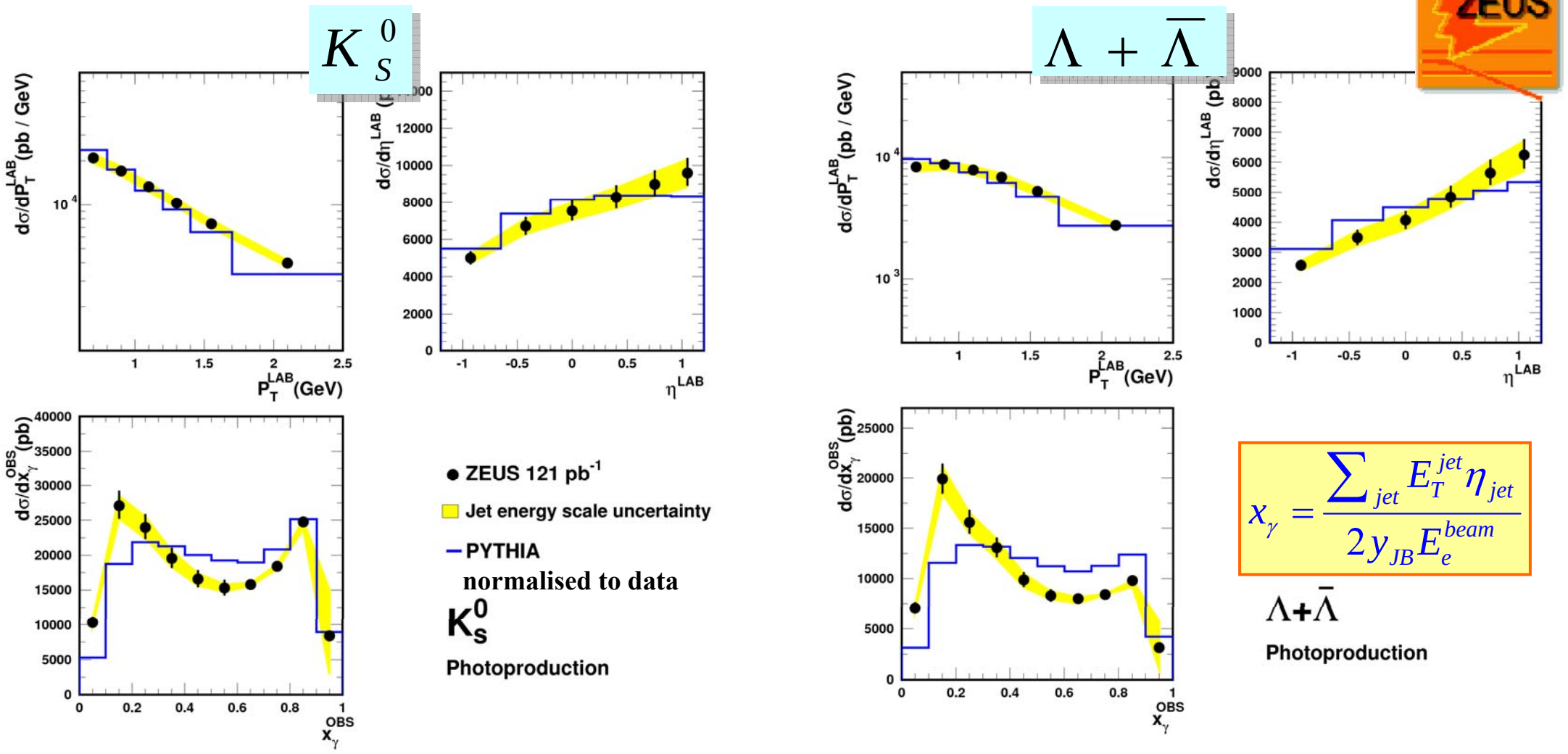


- ARIADNE describes data overall with λ_s=0.3.
  discrepancies in details: K_S at high Q^2, low x_{Bj}, p_T-slope

ZEUS Collab., EPJ C51 (2007) 1

K^0_S and Λ Production in γP

Photoproduction ($Q^2 \approx 0$ GeV^2) : **require 2 jets** ($E_T > 5$ GeV; $|\eta| < 2.4$)



- **PYTHIA (normalised to data) describes overall data features, except at low x_γ^{obs} (resolved)**

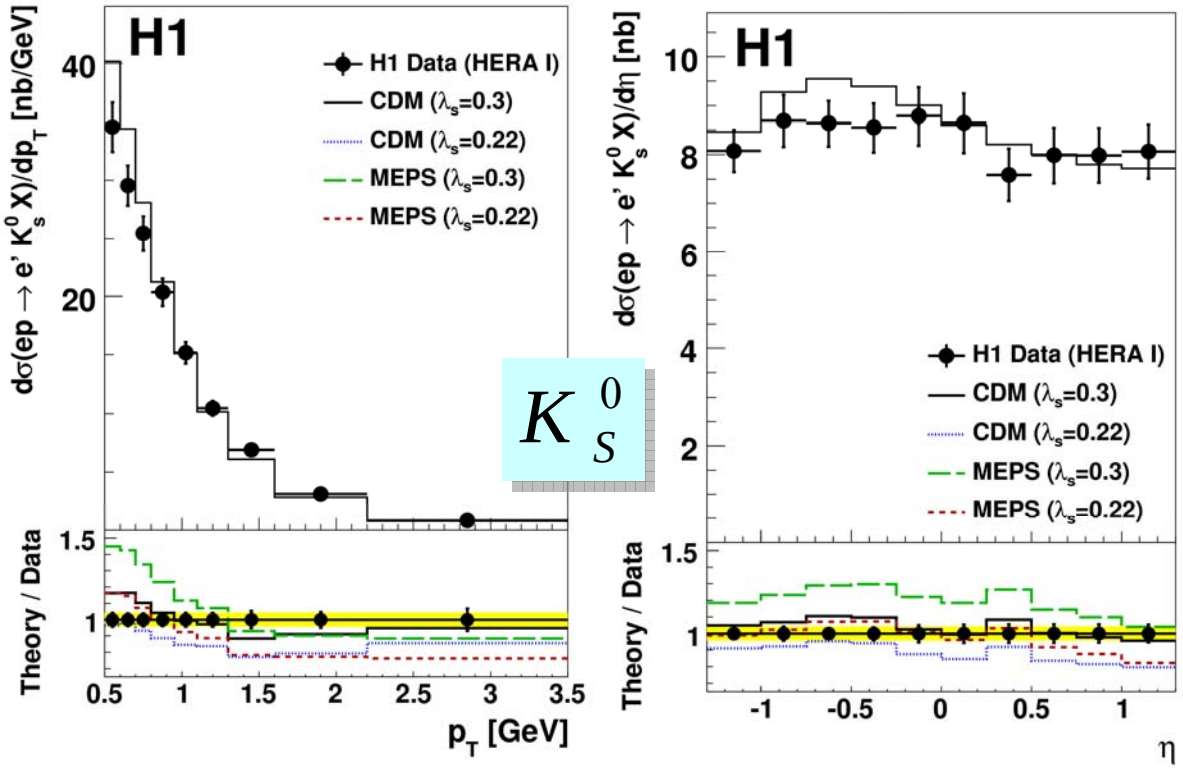
ZEUS Collab., EPJ C51 (2007) 1

K^0_s Production in DIS and γp : H1 and ZEUS

Cross sections in p_T^{lab} and η^{lab}

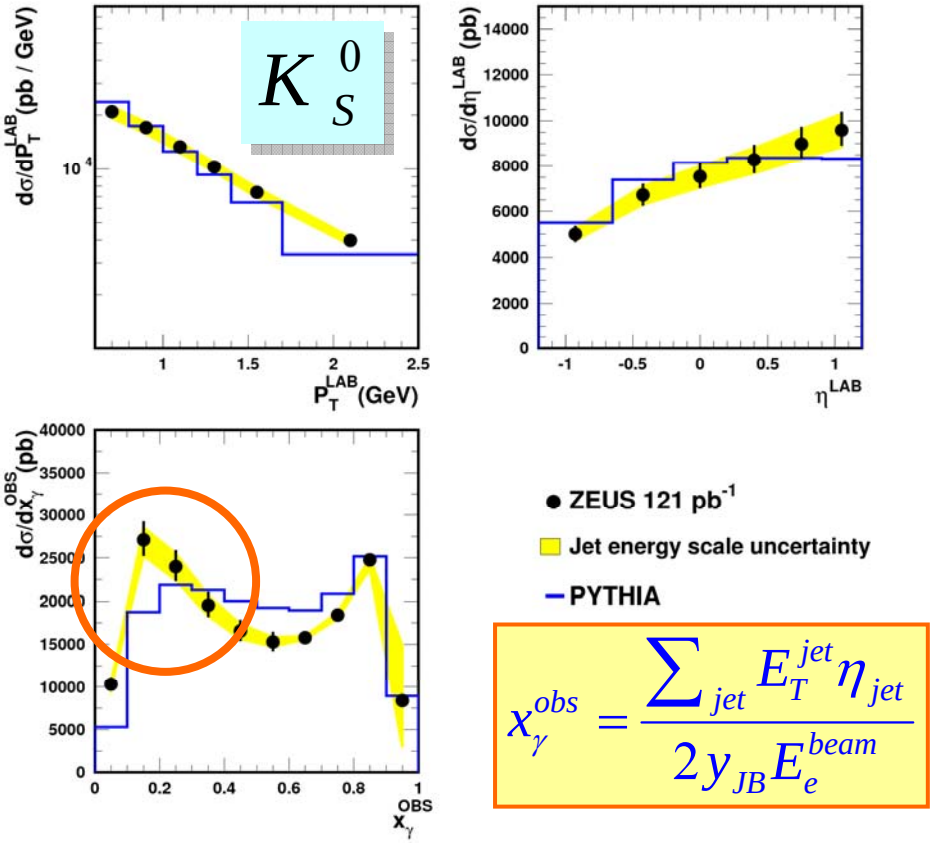
ZEUS Collab., EPJ C51 (2007) 1

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



H1: Prelim. 2008; submitted to EPJ

Photoproduction ($Q^2 \approx 0$ GeV^2) :



$$x_\gamma^{obs} = \frac{\sum_{jet} E_T^{jet} \eta_{jet}}{2 y_{JB} E_e^{beam}}$$

➔ **ARIADNE CDM overall agrees for λ_s=0.3; discrepancies in details: e.g. p_T-slope.**

➔ **PYTHIA (normalised to data) describes overall features, except low x_γ^{obs} (resolved)**

K^0_s and Λ Production (opt)

- Production Mechanisms:
  - direct from proton PDG
  - via boson gluon fusion
  - by perturbative gluon splitting g → ss
  - by non-perturbative string fragmentation
- strangeness suppression factor (γ_S) set to 0.3 (default)
- diquark-anti-diquark suppression = 0.1
- s-diquark/ s-quark suppression = 0.4
- spin-1 / spin-0 diquark suppression = 0.05
- PDF: CTEQ in DIS; GRV and SaS2D for photoproduction
- Monte Carlo : Ariadne (CDM), Lepto (MEPS in DIS), Pythia (MEPS, γp), in general using the ALEPH tune

ZEUS Collab., EPJ C51 (2007) 1

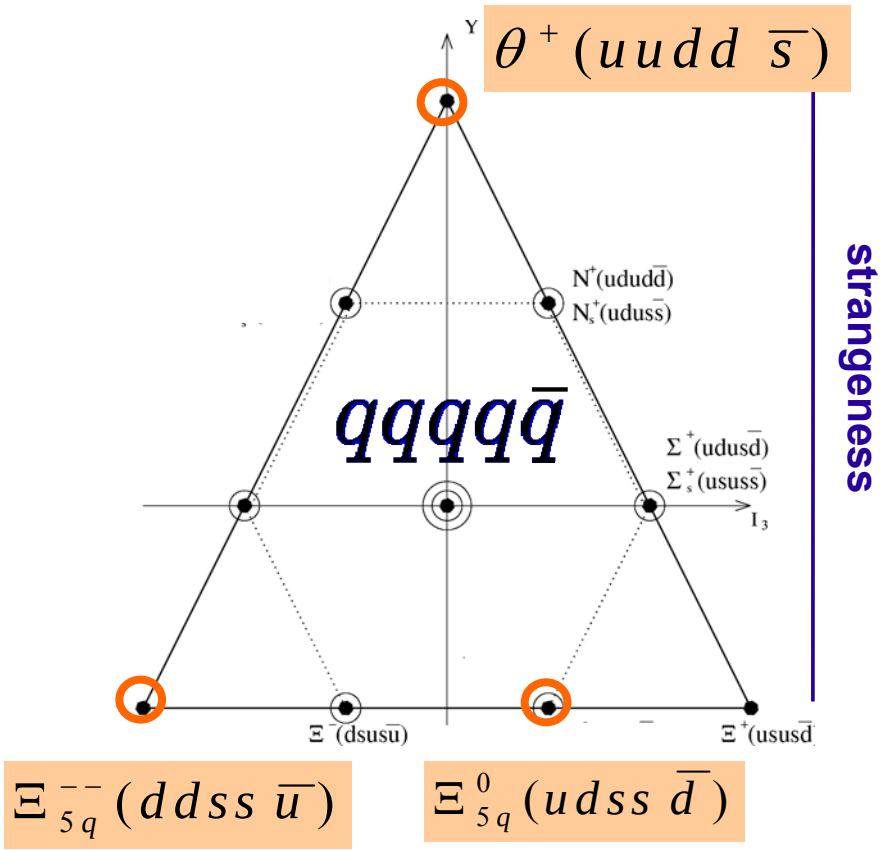
Pentaquarks – Reminder (opt)

Existence of pentaquark states within different theoretical approaches

eg. Chiral Quark Soliton Model (D.Diakonov et al.) predicts an antidecuplet of pentaquarks:

- low mass (1.5–2.1 GeV)
- narrow (≤ 30 MeV)
- exotic quantum numbers

Pentaquark Anti-decuplet



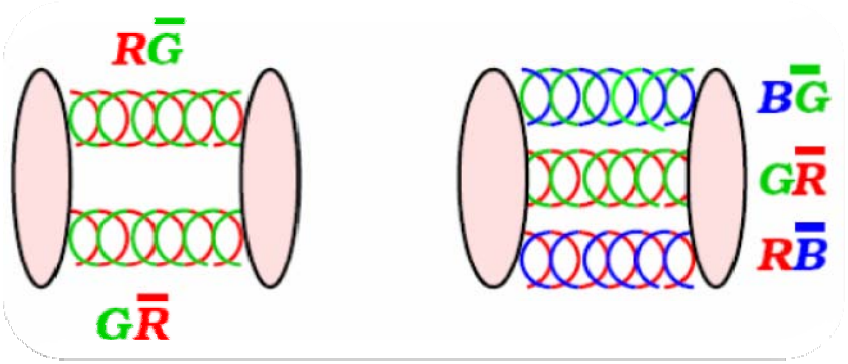
Experimental searches at HERA focused on Θ^+, Ξ^{--}, Ξ^0

→ **many positive and negative results exist on** Θ^+ **besides HERA ...**

D.Diakonov et al. Z. Phys A359, 1997, 305;
D. Diakonov, V. Petrov, Phys. Rev. D69, 2004, 094011

Glueballs in $K^0_S K^0_S$ Resonances ? (ref)

The $K^0_S K^0_S$ system is expected to couple to scalar and tensor glueballs



K^0_S: has S=0, P=-1, C=+1

$K^0_S K^0_S$: has P=+1, C=+1 → J = even

$K^0_S K^0_S$ bound states ➔ J^{PC}: 0^{++}(scalar), 2^{++} (tensor) …

$P = (-1)^{(L+1)}$	Parity
$C = (-1)^{(L+S)}$	Charge Conjugation
$J = L \oplus S$	J: Total Angular Momentum
	L: Orbital Angular Momentum
	S: Total Spin ($q\bar{q} \Rightarrow$ 0, 1)

- Lattice QCD predicts: Lightest glueball candidates:
  - $J^{PC} = 0^{++}$ → mass 1730 ± 100 MeV.
  - $J^{PC} = 2^{++}$ → mass 2400 ± 120 MeV.

- Experimentally, four states with $J^{PC} = 0^{++}$ and I=0 are established (PDG)

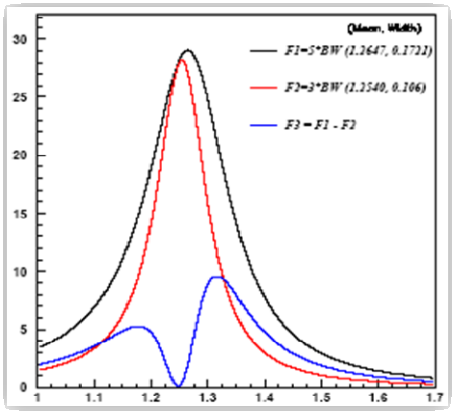
  $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$

- **Question:**
  what's the mixing fraction of mesons and glueballs?
- **Hybrids? Tetraquarks ? …**

Fitting: use Breit-Wigner with interference

	Coherent States		
	$f_2(1270)$	$a_2(1320)$	$f_2(1525)$
Isospin I =	0	1	0
Quark Content	$(u\bar{u}+d\bar{d})/\sqrt{2}$	$(u\bar{u}-d\bar{d})/\sqrt{2}$	$s\bar{s}$
Charge Factor	$(\frac{2}{3}\times\frac{2}{3}+\frac{1}{3}\times\frac{1}{3})\frac{1}{2}$	$(\frac{2}{3}\times\frac{2}{3}-\frac{1}{3}\times\frac{1}{3})\frac{1}{2}$	$\frac{1}{3}\times\frac{1}{3}$
Amplitude ratio	5 BW	-3 BW	2 BW

Destructive interference



Function = a {5 * BW_$f_2(1270)$ – 3 * BW_$a_2(1320)$ + 2 * BW_$f_2(1525)$}^{2}
+ b {BW_$f_0(1710)$}^{2}
+ c Background U(M)

a b c are free parameters

BW is Relativistic Breit-Wigner function:

$$F(M) = \frac{m\sqrt{\Gamma}}{m^2 - M^2 - im\Gamma}$$

Faiman, D. and Lipkin, H. J. and Rubinstein, H. R., Phys. Lett. **B59**, 269 (1975)

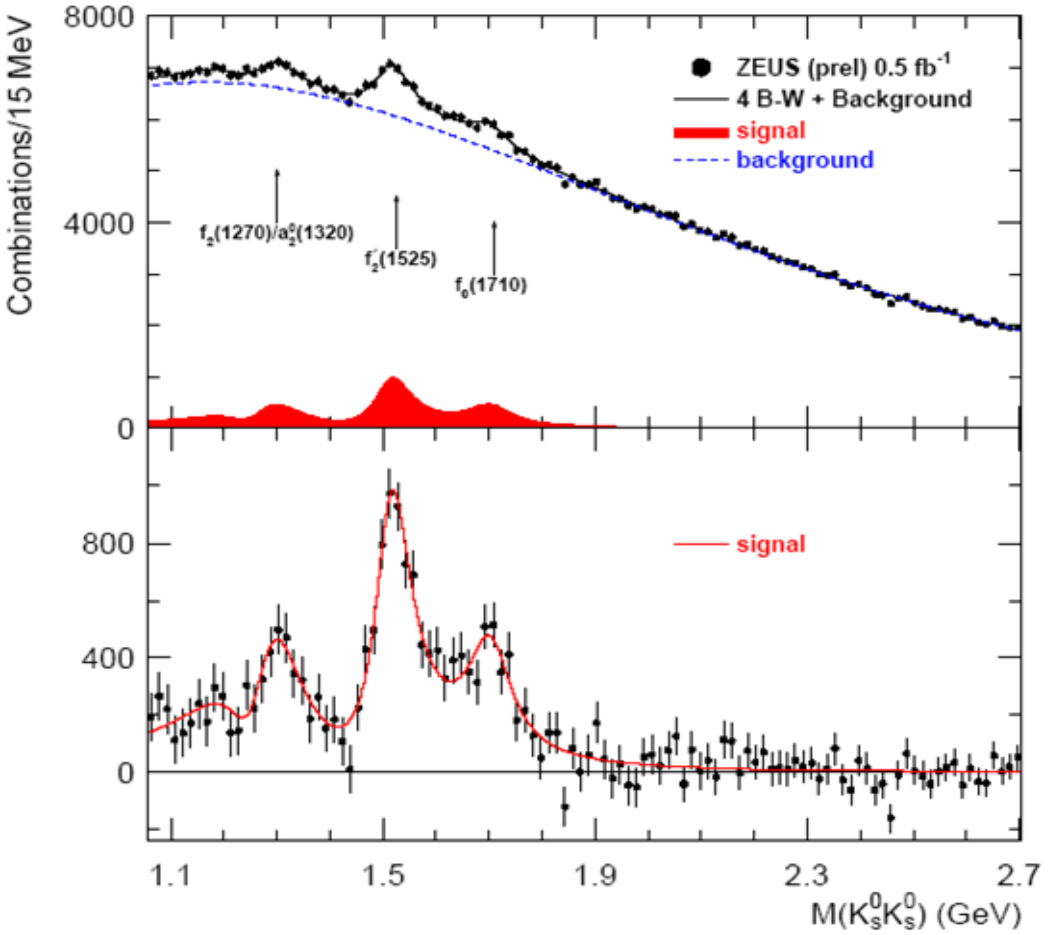
Fitting functions

- Modified Relativistic Breit-Wigner (MRBW) function F(M) + BGRND U(M) :

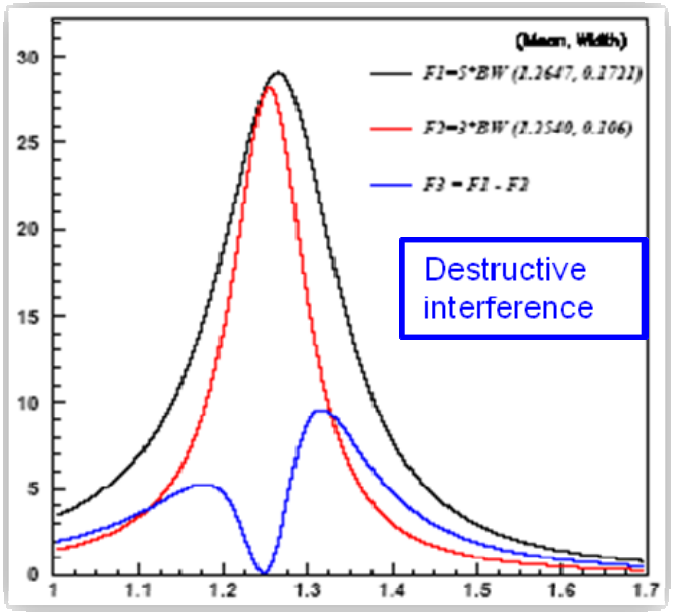
$$F(M) = \sum_{i=1}^{3} C_i \left(\frac{m_{*,i}\Gamma_{d,i}}{(m_{*,i}^2 - M^2)^2 + m_{*,i}^2\Gamma_{d,i}^2} \right)$$

$$U(M) = A \cdot (M - 2m_{K_S^0})^B \cdot \exp\left(-C(M - 2m_{K_S^0})\right)$$

- C_i is the amplitude of the resonance
- $m_{*,i}$ is the mass of resonance
- $\Gamma_{d,i}$ is the effective resonance width
- M is the $K^0_s K^0_s$ invariant mass



$X^2/ndf = 86/110$



Improved fitting in 1270 and 1420 region, where destructive and constructive interference are well described.

Structures in $K^0_S K^0_S$ Resonances

Fit	No interference		Interference		PDG 2007 Values	
χ^2/ndf	96/95		86/97			
in MeV	Mass	Width	Mass	Width	Mass	Width
$f_2(1270)$	1304 ± 6	61 ± 11	1268 ± 10	176 ± 17	1275.4 ± 1.1	$185.2^{+3.1}_{-2.5}$
$a_2^0(1320)$			1257 ± 9	114 ± 14	1318.3 ± 0.6	107 ± 5
$f_2'(1525)$	$1523 \pm 3^{+2}_{-8}$	$71 \pm 5^{+17}_{-2}$	$1512 \pm 3^{+1.4}_{-0.5}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1692 \pm 6^{+9}_{-3}$	$125 \pm 12^{+19}_{-32}$	$1701 \pm 5^{+9}_{-2}$	$100 \pm 24^{+7}_{-22}$	1724 ± 7	137 ± 8

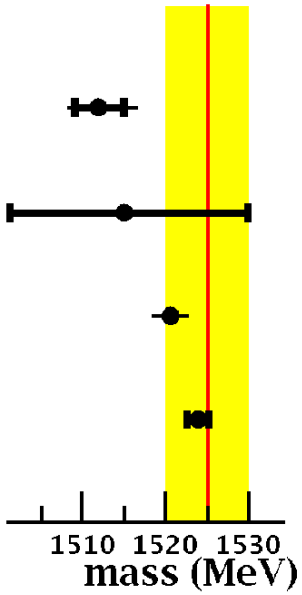
Table 1: *The measured masses and widths for the $f_2(1270)$, $a_2^0(1320)$, $f_2'(1525)$ and $f_0(1710)$ states using $K^0_S K^0_S$ decays as determined by one fit neglecting interference and another one with interference as predicted by SU(3) symmetry arguments*

- Masses of f_2'(1525) and f_0(1710) found bit low, but widths consistent with PDG
- f_0(1710) mass, seen at 5 sigma, is consistent with $J^{PC}=0^{++}$ glueball candidate

ZEUS Collab., DESY 08-068

Summary $f_2(1525)$ and $f_0(1710)$ states

$f_2(1525)$



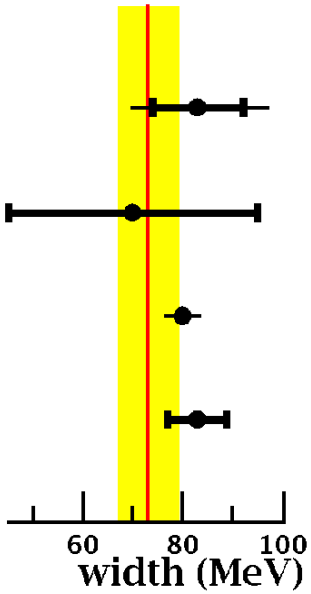
e p ZEUS

Central p p Production

e^+e^- experiments

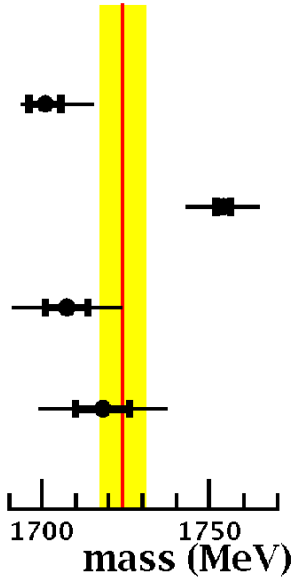
K-meson experiments

PDG 2007



← ZEUS low mass

$f_0(1710)$



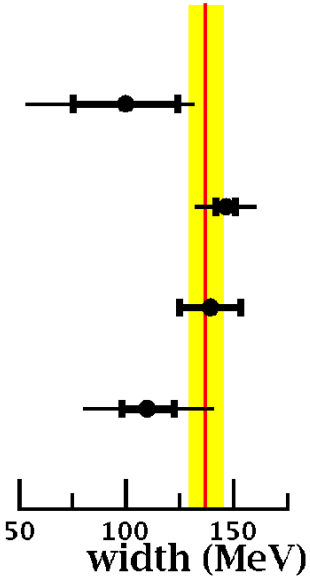
e p ZEUS

e^+e^- BES Collab.

e^+e^- other Collab.

p p, π p experiments

PDG 2007

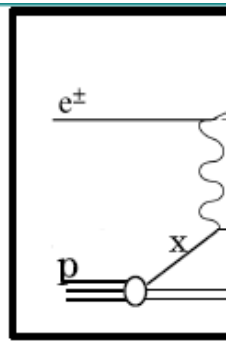


← ZEUS low mass

← BES high

K*(892) Production in DIS

DATA 05&06&07 (L = 301 pb^{-1})
DST5 with 3.3.6 h1oo version used
Electron Sigma Method used



Kinematic Cuts

- $5 < Q_e^2 < 100$ GeV²
- $0.1 < y_{e\Sigma} < 0.6$
- Scattered electron selection
  - $E_e > 11$ GeV
  - $156^\circ < \theta_e < 173^\circ$
  - SPACAL fiducial cuts applied

Technical Cuts

- S61 Trigger
  - electron ($E_e > 6$ GeV) SpaCal
  - at least 1 high momentum track candidate
- $35 < E\text{-}P_z < 70$ GeV
- $-35 < z_{vtx} < 35$ cm
- Scattered electron selection
- $E_{had} < 0.5$ GeV, $R_\theta > 12$ cm, $R_{cluster} < 4$ cm

K^0_s Selection

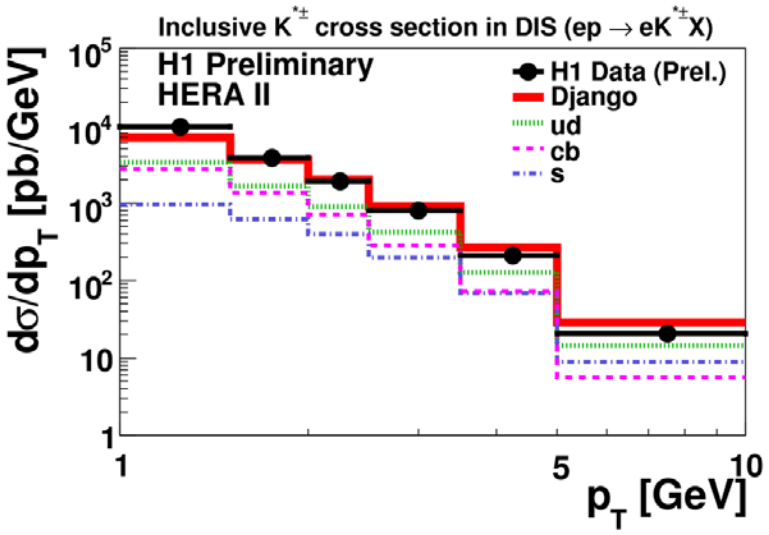
- Use h1oo K0-Finder
- Pairs of oppositely charged secondary c
- $p_T > 0.12$ GeV/c , $|\eta| < 1.5$
- Λ (cut on $(M_{p\pi}\text{-}1.115) < 0.012$ GeV)
- γ conversion cut on $M_{e+e-} > 0.05$ GeV
- $p_{T(\pi\pi)} > 0.5$ GeV
- Armenteros $p_\perp > 0.11$ GeV
- $|\cos(\theta^*)| < 0.95$
- $\chi^2 < 5.4$
- $\Delta(dca) > 0.5$
- Radial decay length > 2 cm
- $0.470 < M_{K0s} < 0.520$ GeV

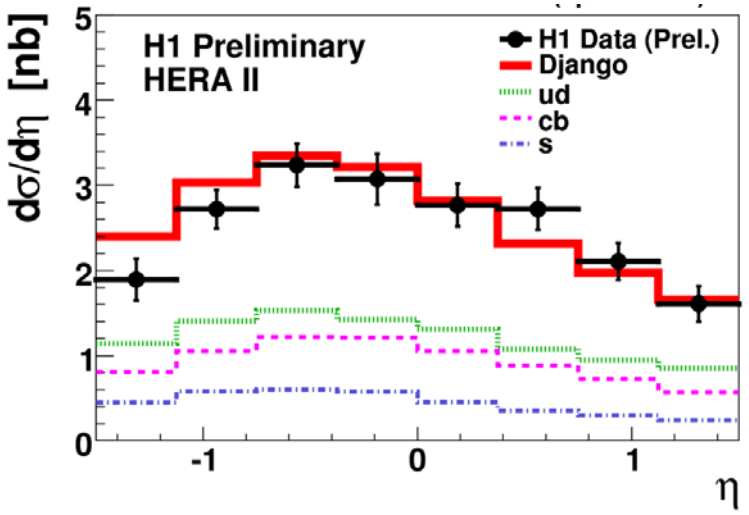
K*(892) Production: Quark contributions (opt)

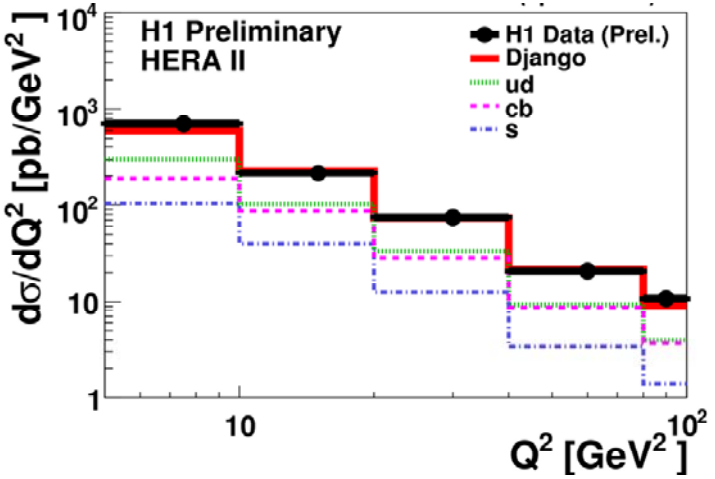
H1 Collab., Prelim 2008

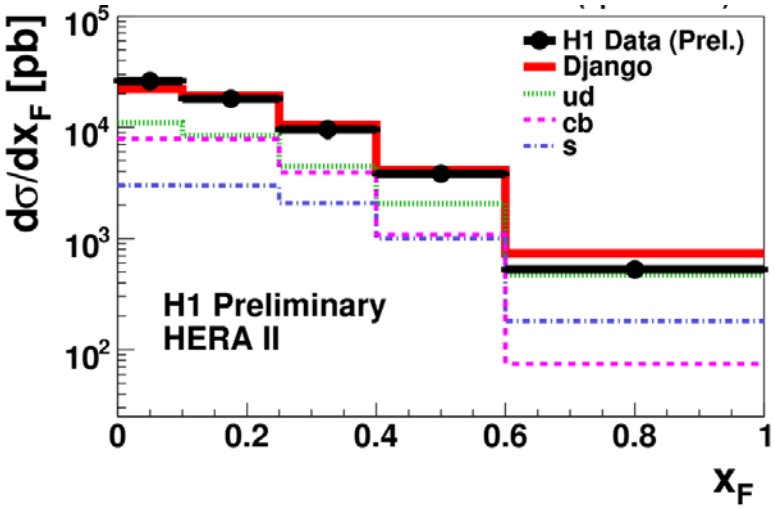
$K^{*\pm} \rightarrow K^0_S \pi^\pm$

Inclusive cross sections





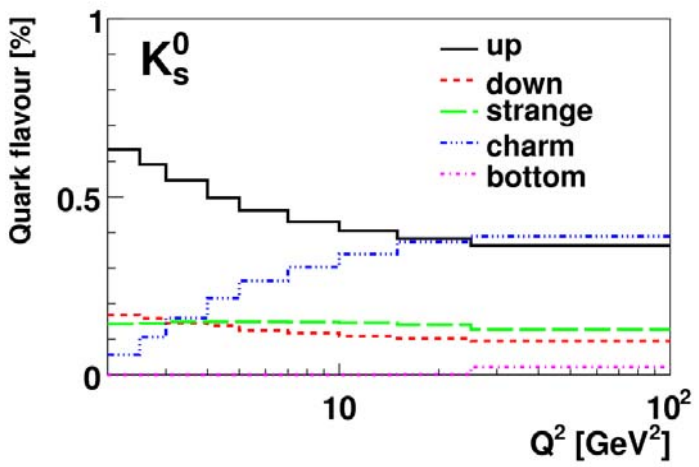


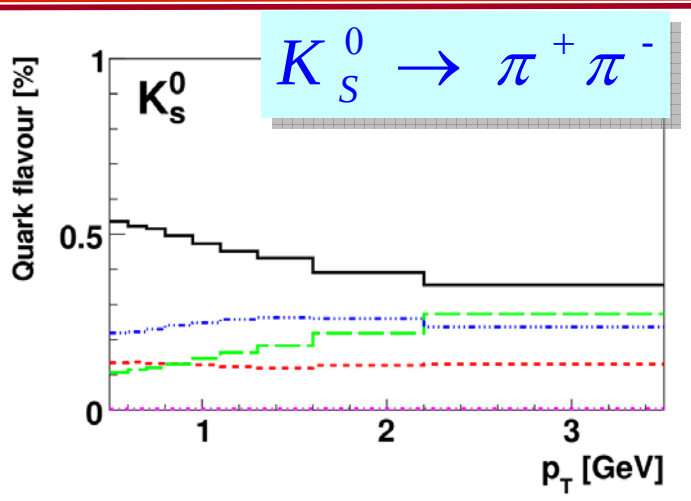


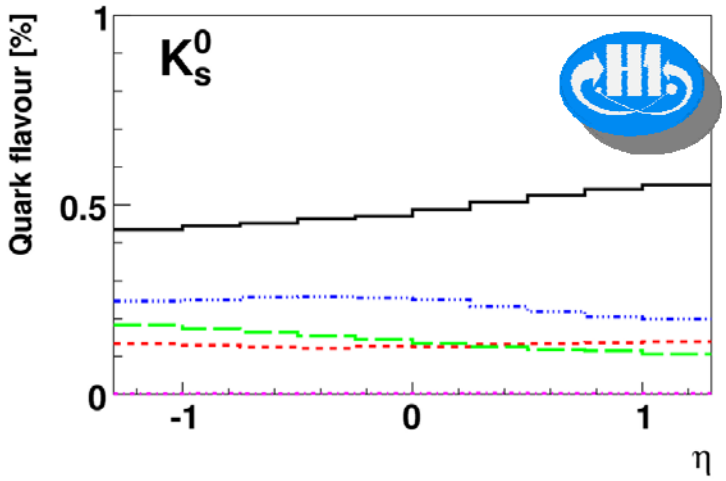
$$x_F = \frac{2P_L}{W}$$

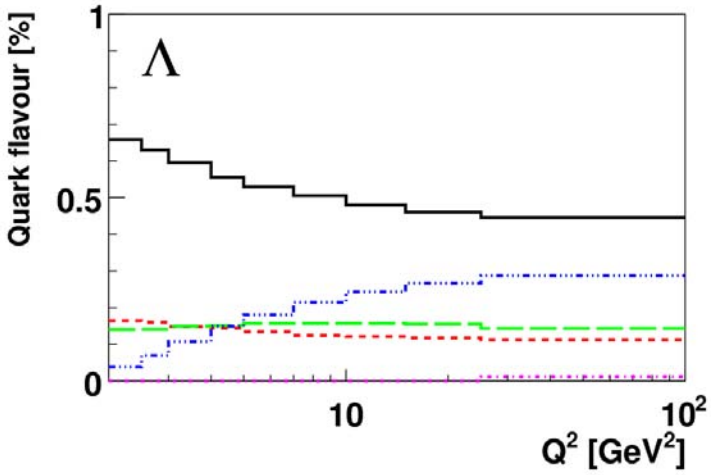
- **quark contributions:** at low scales: u,d dominate; at large scales, charm and light quarks become equivalent → difficult to extract s-content of proton

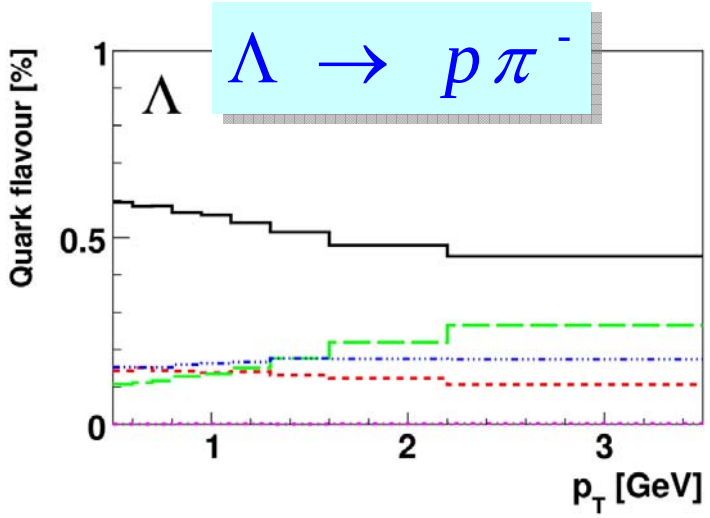
K_S , Λ Production: Quark contributions (opt)

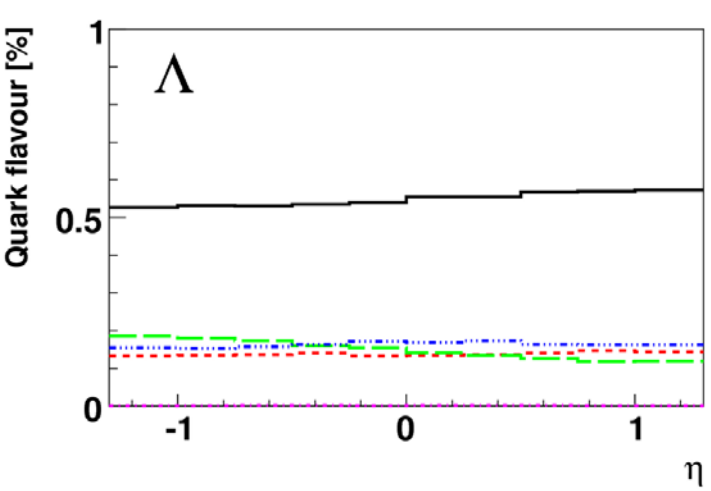








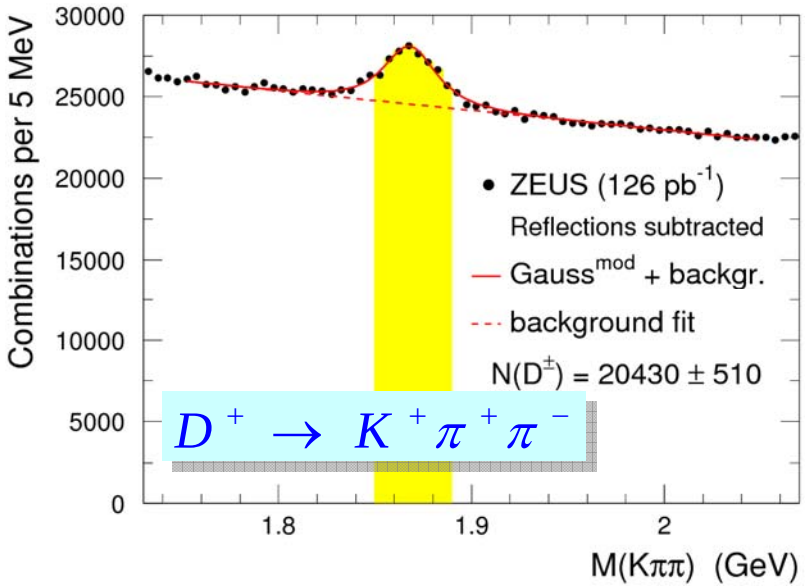


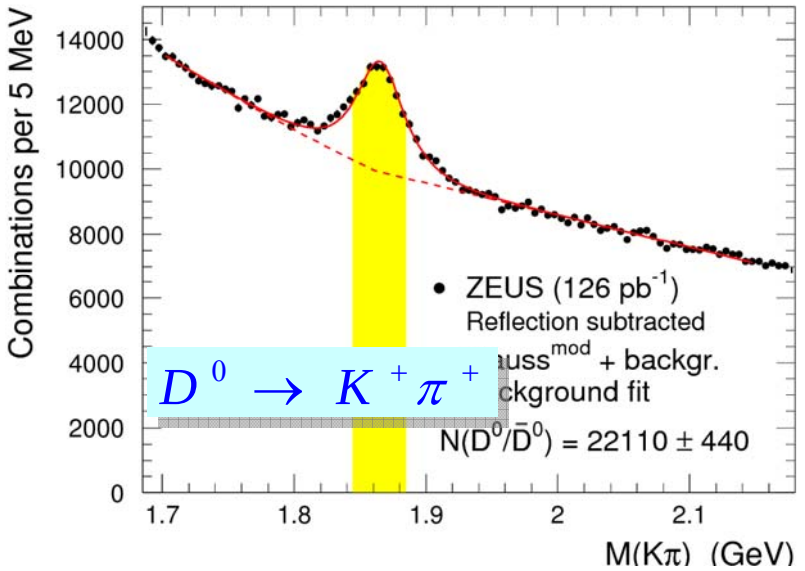


- **quark contributions:** at low scales: u,d dominate; at large scales, charm and light quarks become equivalent → difficult to extract s-content of proton

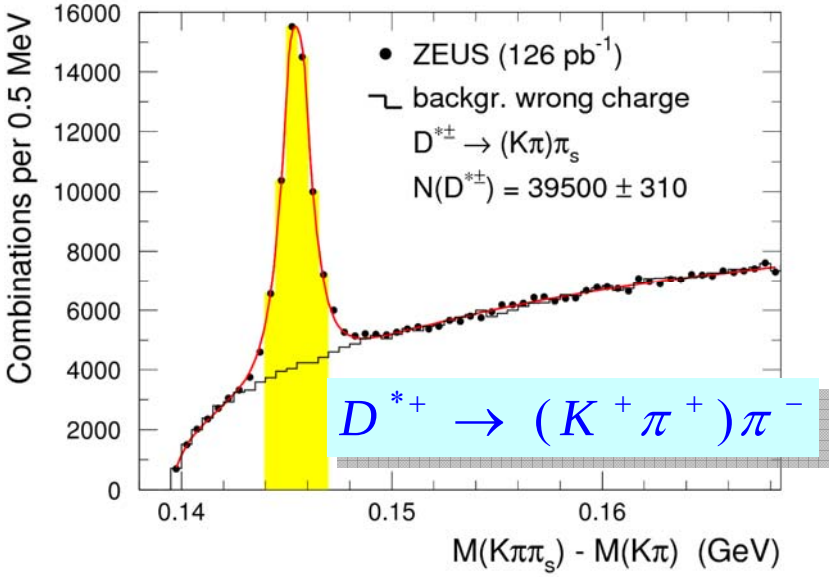
Excited Charmed Mesons (opt)

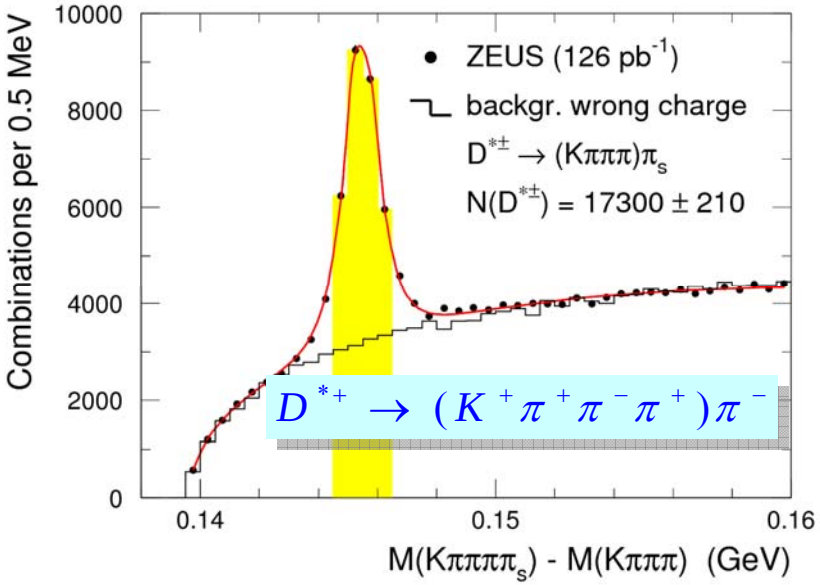
Signals used: $D^+ \to K^- \pi^+ \pi^+$ and $D^0 \to K^- \pi^+$





$D^{*+} \to (K^- \pi^+)\pi^+$ and $(K^- \pi^+ \pi^- \pi^+)\pi^+$



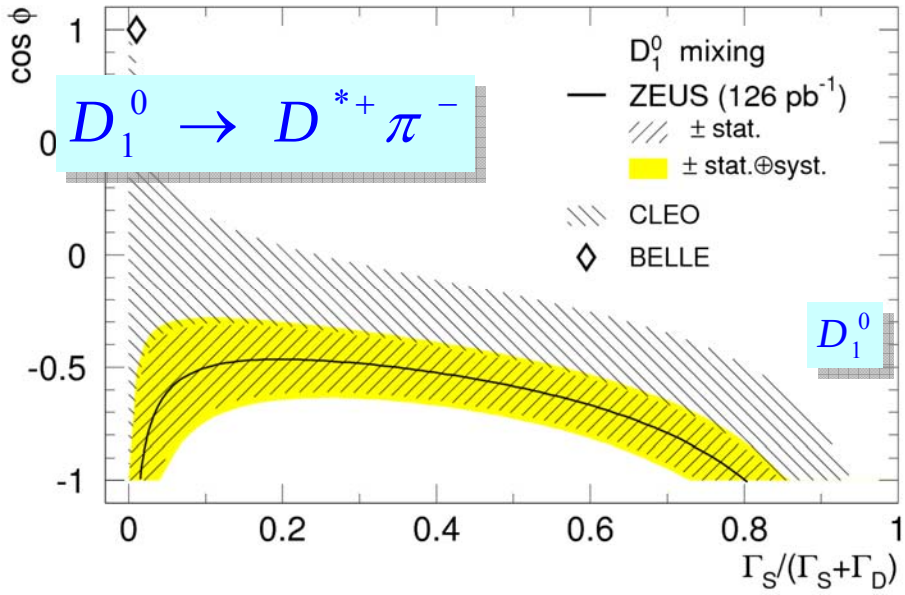


ZEUS DESY-08-093.

Excited Charmed Mesons (opt)

cos ϕ vs $r = \Gamma_S/(\Gamma_S + \Gamma_D)$

- **Cosine of relative phase of S- and D-wave amplitudes**



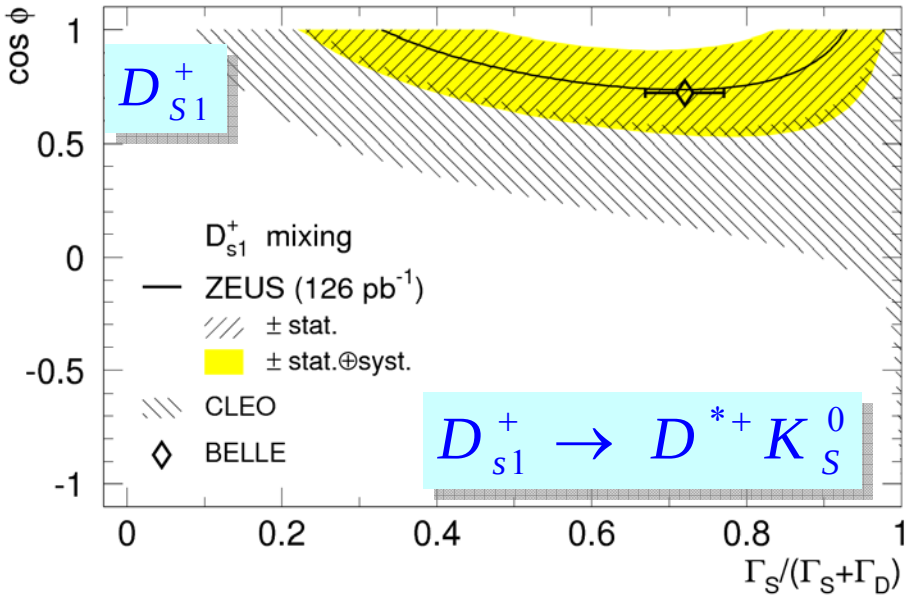
ZEUS measured:

100 +- 13 events in $D^+_{s1} \to D^{*+} K^0_S$

Fits for helicity parameter between K^0_S and π_s in D* rf $dN \sim (1 + h \cos^2\theta)$ gives

$$h(D^+_{s1}) = -0.74^{+0.23}_{-0.17}(stat)^{+0.06}_{-0.05}(sys)$$

h≠0 suggests mixture of two 1^+ states, D+S waves, eg. $D_{s1}(2536)^+$ and $D_{s1}(2460)^+$



➔ this is consistent

*** with Belle and CLEO values**

*** not with h=3 for pure D 1^+ state**

*** not really with h=0, for pure S 1^+**