Spectroscopy Results from HERA

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on behalf of the H1 and ZEUS Collaborations

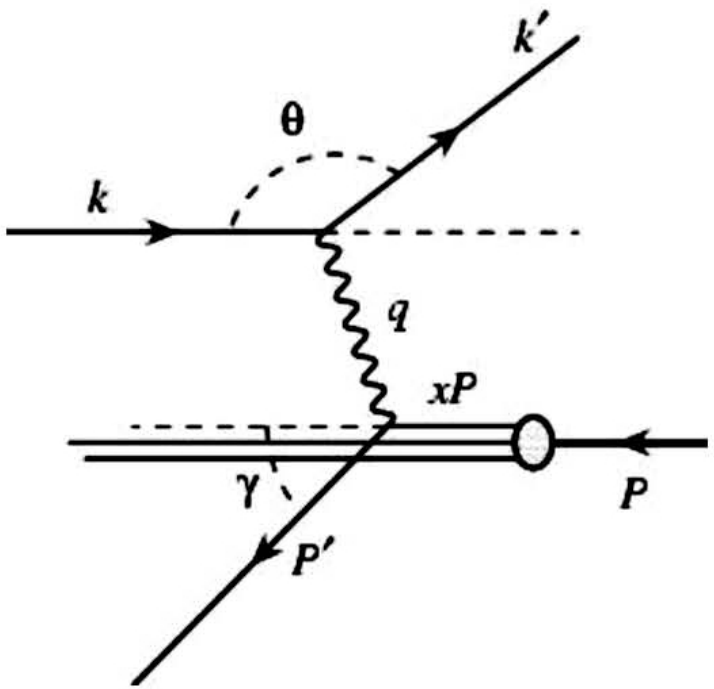
PhiPsi08 at Laboratori Nazionali di Frascati

10 April 2008

- **H1 and ZEUS at HERA**
- **Hadron production**
- **Tetraquark States ?**
- **Pentaquark States ?**
- **Outlook**

$e^{\pm}p$ – Kinematics at HERA

27.6 GeV electrons/positrons on 920(820) GeV protons



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

$$x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

$$s = (p + k)^2 \qquad Q^2 = x \cdot y \cdot s$$

Deep Inelastic Scattering (DIS):

Neutral current (NC) via γ/Z^0 exchange

Charged current (CC) via $W^{\pm}$ exchange

Photoproduction: $Q^2 \approx 0$

Q^2 = exchanged momentum (squared)

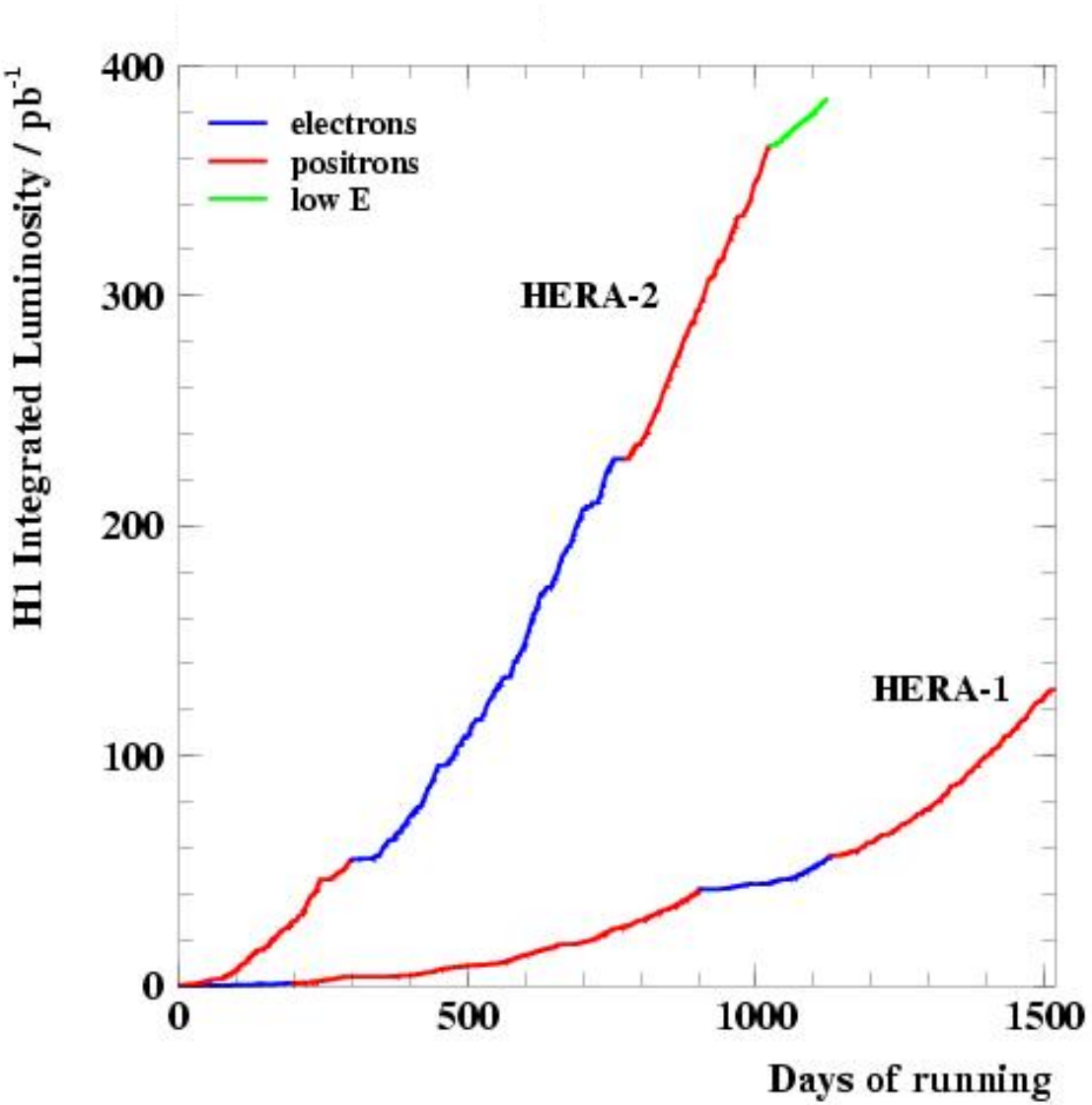
x = Bjorken scaling variable

y = inelasticity scaling variable

$\sqrt{s}$ = center of mass energy (~320 GeV)

W = photon-proton center of mass energy

HERA Luminosities



HERA I: **unpolarised e± beams**

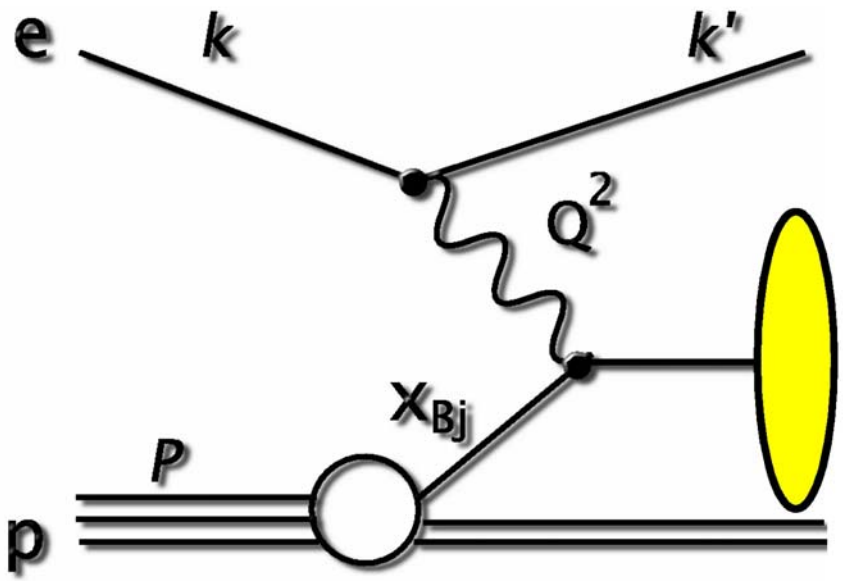
HERA II: **polarised e± beams**

Gated luminosities

e±p	H1	ZEUS
HERA I	128 pb^{-1}	143 pb^{-1}
HERA II	385 pb^{-1}	407 pb^{-1}

~ 0.5 fb^{-1} per experiment

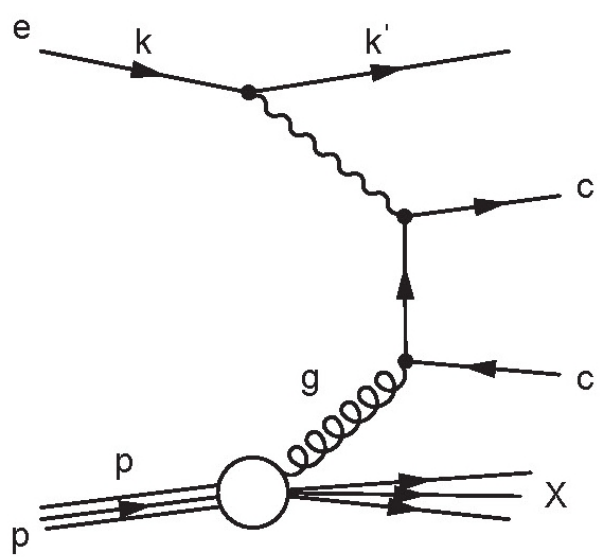
Hadron Production at HERA



Hadronisation processes leading to hadronic final states (non-perturbative QCD)

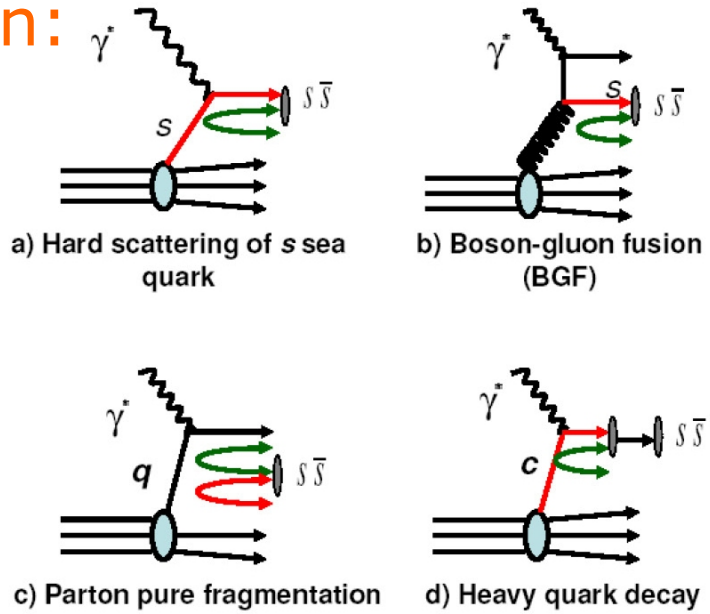
Heavy quark production however dominated by photon-gluon processes

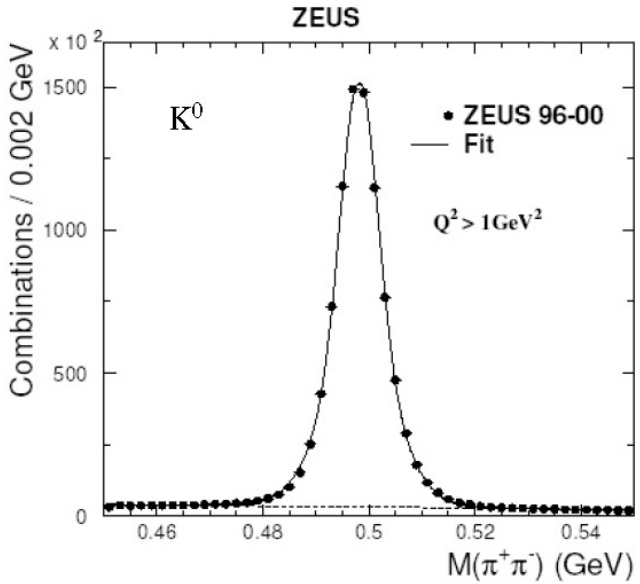
(perturbative QCD)



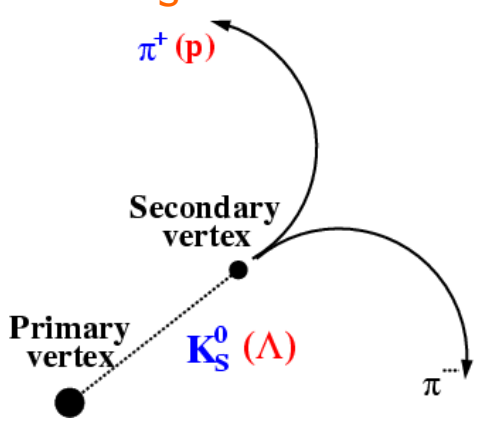
Strangeness

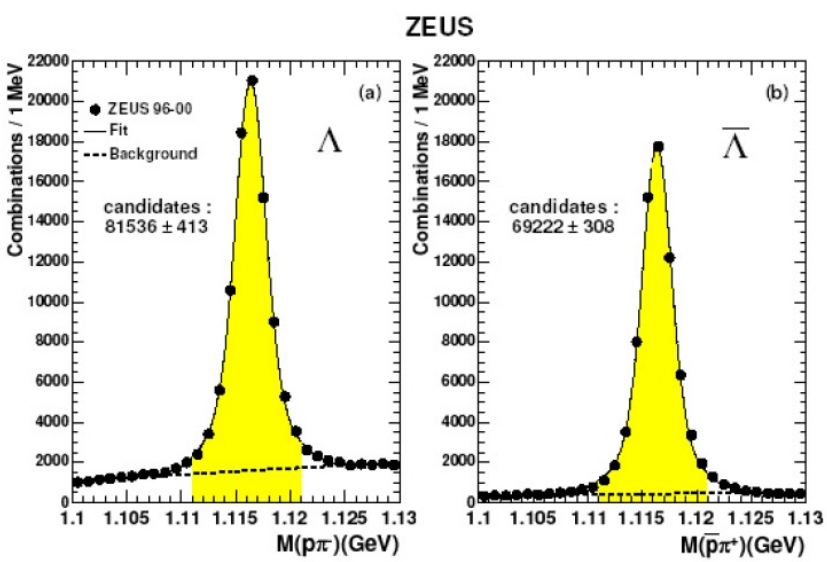
Production:





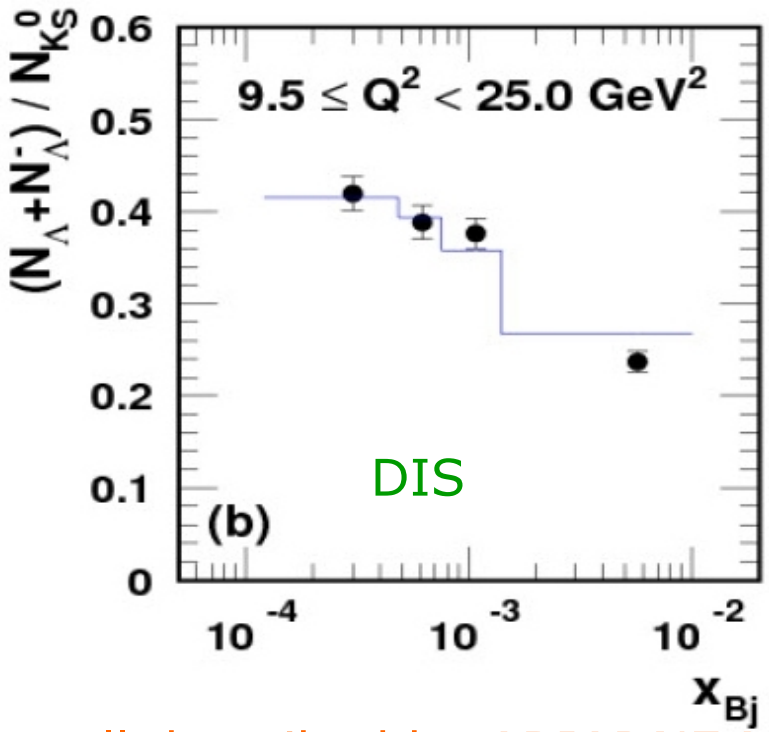
Observation of K_s^0's and Λ's:

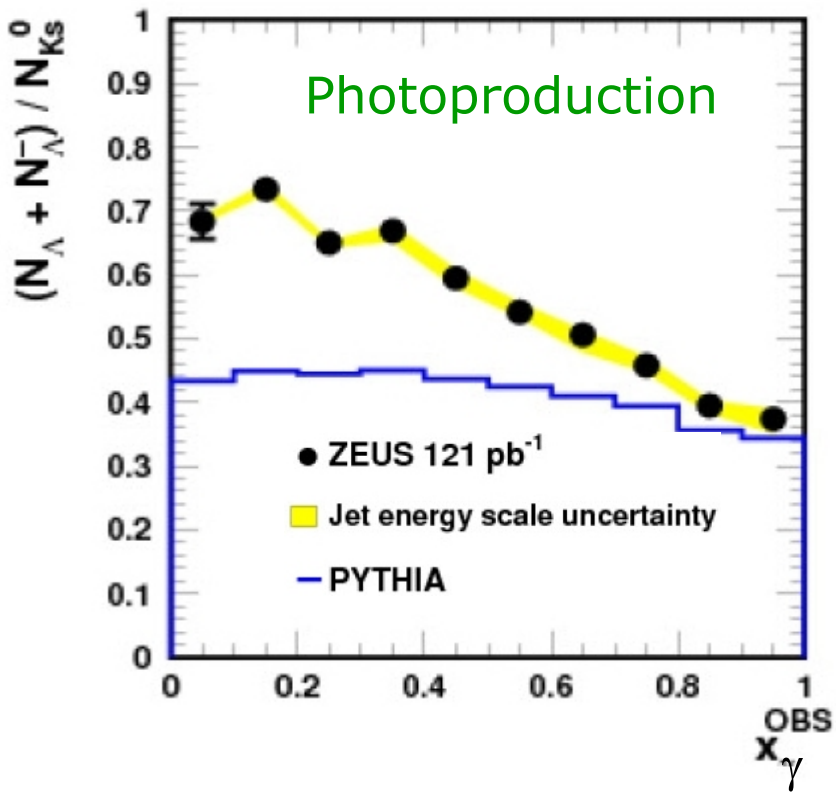




Strangeness Results

Baryon to meson ratio: $(\Lambda + \bar{\Lambda})/K^0_s$





fairly well described by ARIADNE MC (strangeness suppression factor $\lambda_s = 0.3$)

new production mechanism needed at low x_γ^{OBS}

Other results:

(similar ones from H1)

full sets of cross sections vs event/particle variables

baryon to meson ratio similar to e^+e^- measurements

no baryon-antibaryon asymmetry observed

no evidence for Λ transverse polarisation

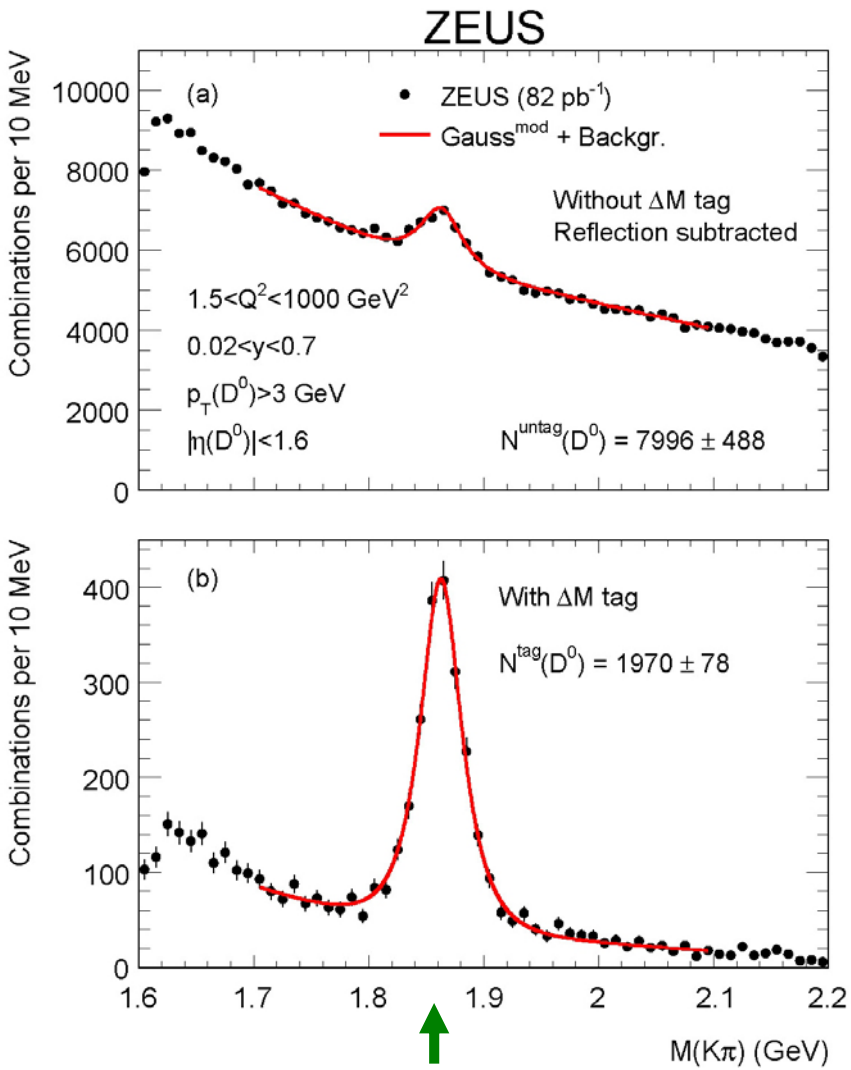
Charm Production

$D^0 \rightarrow K^- \pi^+$
$D^{*+} \rightarrow D^0 \pi_s^+$
$D^+ \rightarrow K^- \pi^+ \pi^+$
$D_s^+ \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+$
$\Lambda_c^+ \rightarrow K^- p \pi^+$

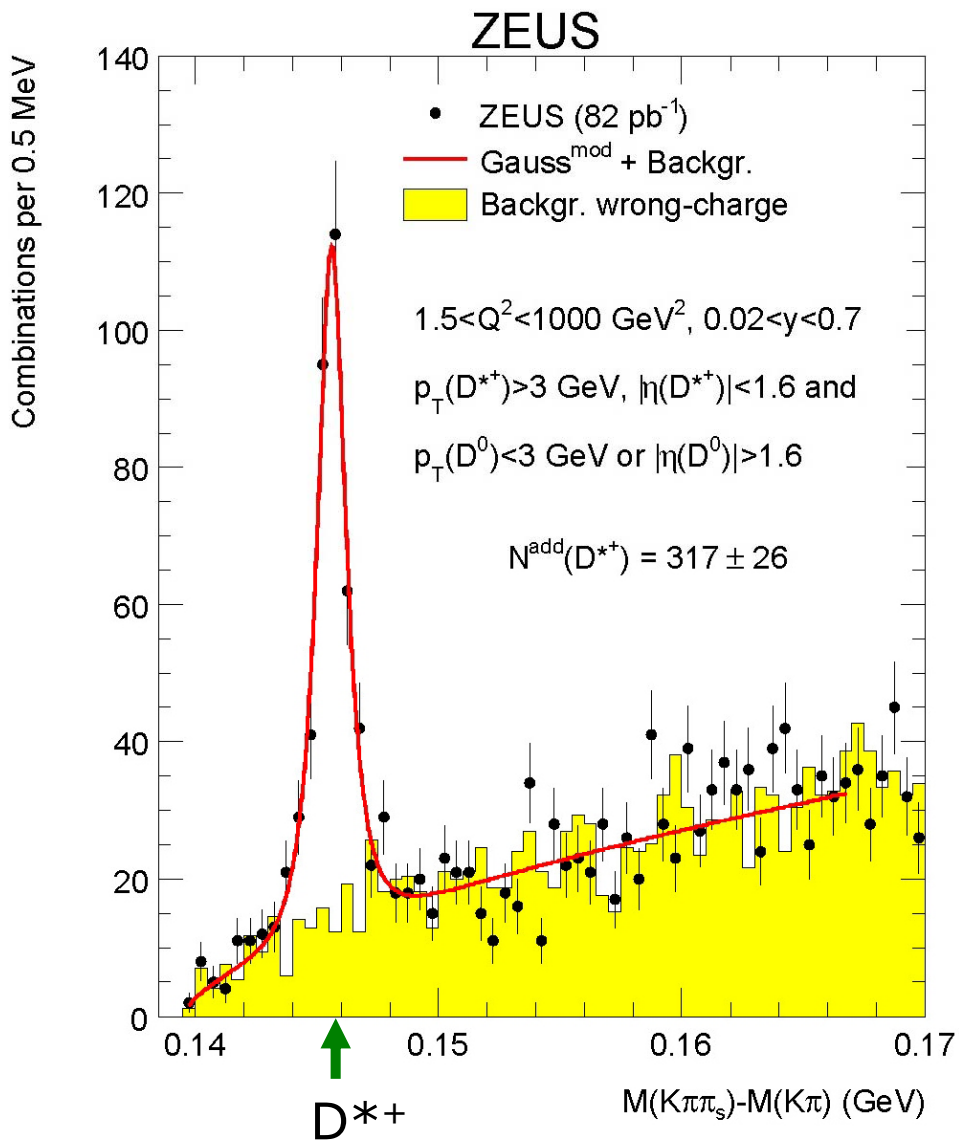
- charm fragmentation ratios
- charm hadronisation fractions
- .. numerous other QCD results

  (cross sections vs QCD NLO, F_2^{cc}, ..)

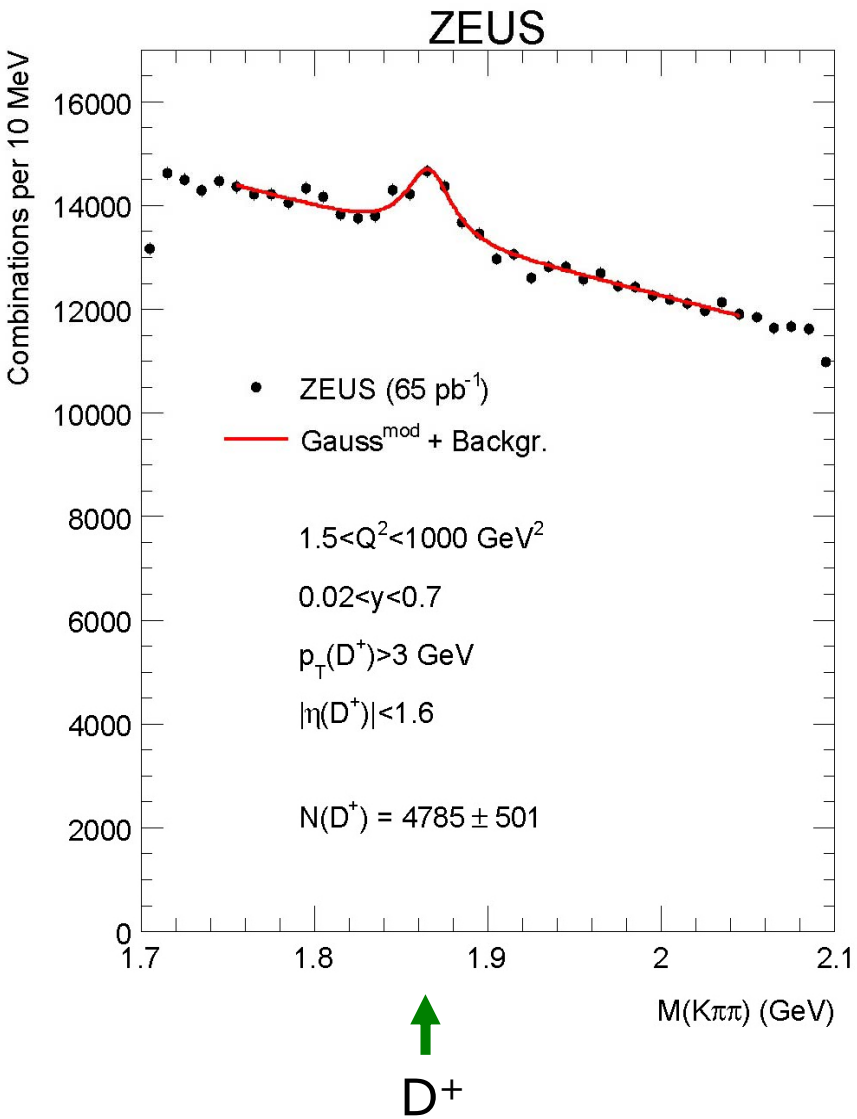
D^0 and D* Production

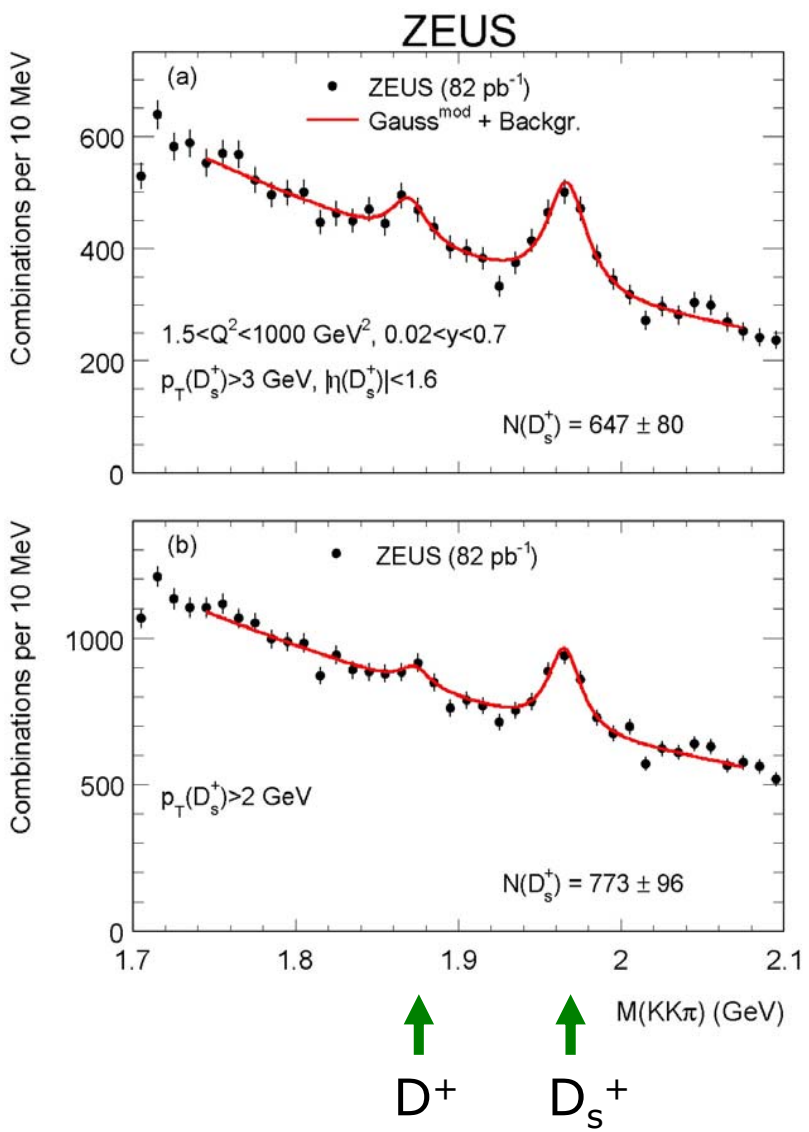


ΔM tag from $D^{*+} \rightarrow D^0 \pi_s^+$ events

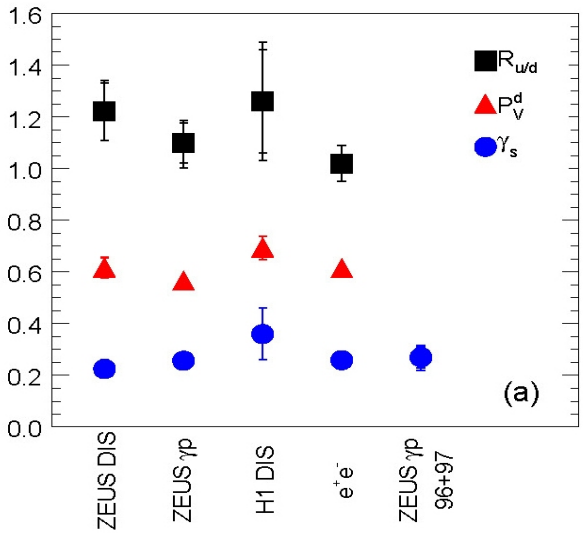


D^+ and D_s^+ Production



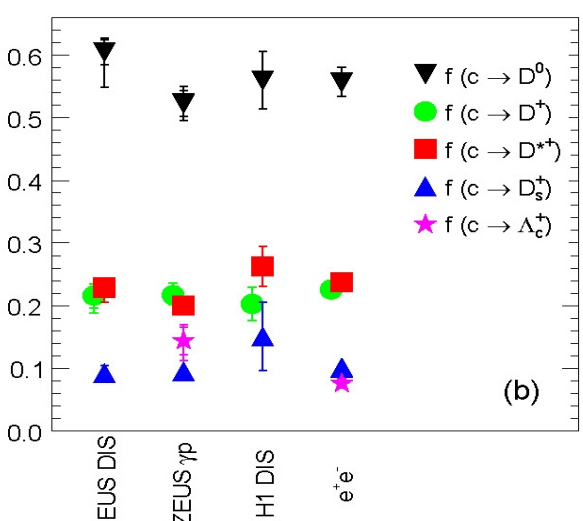


Charm Fragmentation



Ratios:

- neutral to charged D mesons → *u* and *d* produced ~equally in charm fragmentation
- fraction charged D's in vector state < naïve ¾
- strangeness suppression factor



Fractions:

- generally consistent with expectations
- agreements ZEUS – H1 – e^+e^-
- fragmentation ~independent of the hard subprocesses

Gluon and Quark States

The best known hadrons are well explained by the Standard Model

Particles made only from gluons, or from more than 3 quarks are not excluded

Since gluons carry both color and anti-color, 2 or 3 may form color singlet "glueballs"

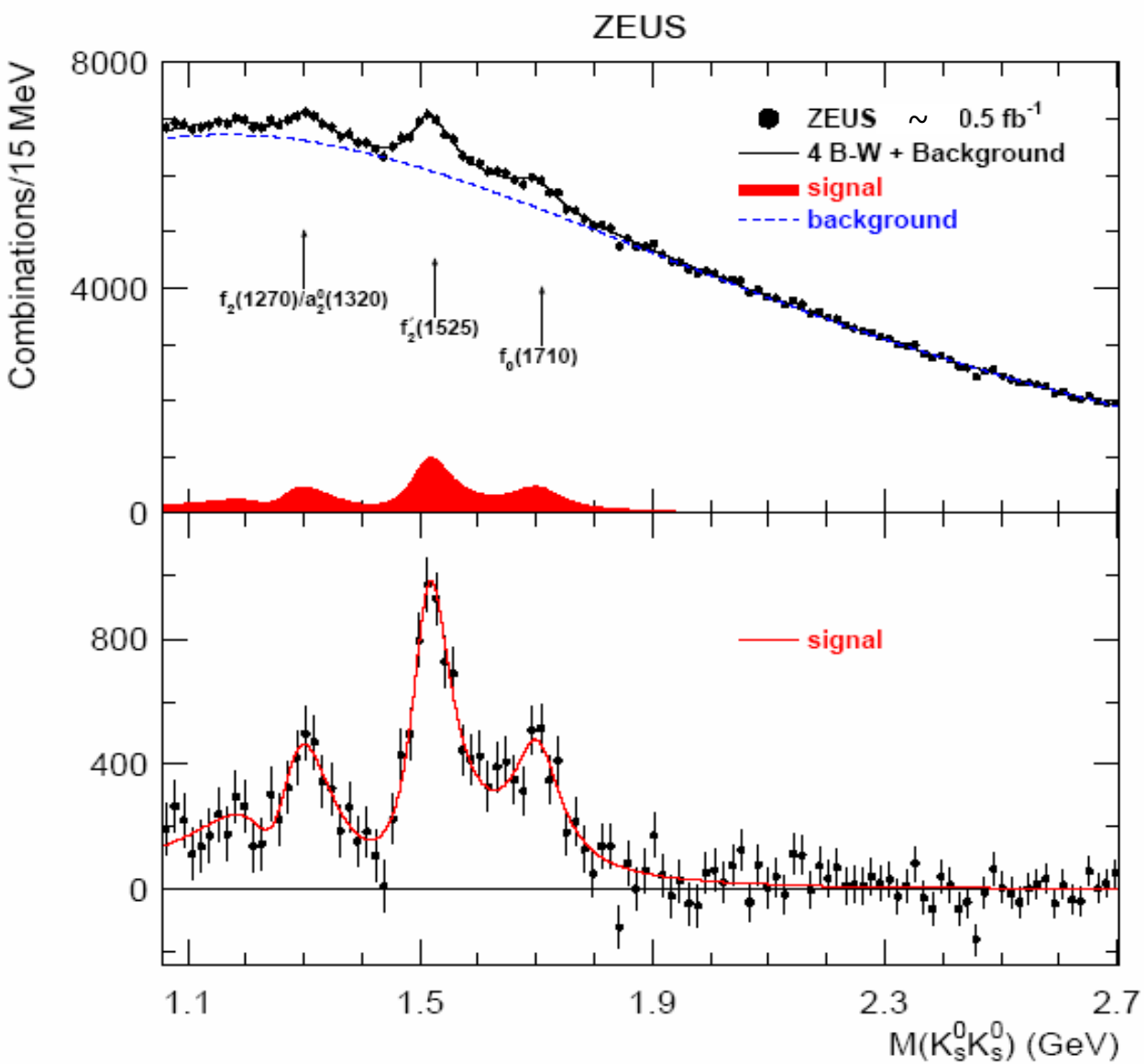
Lattice QCD calculations predict:

lightest glueball $J^{PC} = 0^{++}$ in mass range 1450-1750 MeV

next: $J^{PC} = 2^{++}$ in mass range 2300-2600 MeV

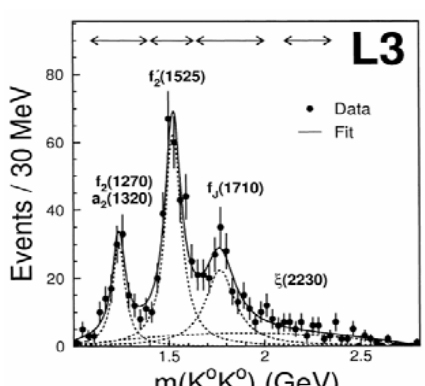
$K_s^0 K_s^0$ bound states: $J^{PC} = 0^{++}$ (scalar), 2^{++} (tensor), .. hence may couple to glueballs

$K_s^0 K_s^0$ Resonant States



Bret-Wigner functions, with interference terms included

states $f'_2(1525)$ and $f_0(1710)$ clearly seen



$K_s^0 K_s^0$ Resonance Results

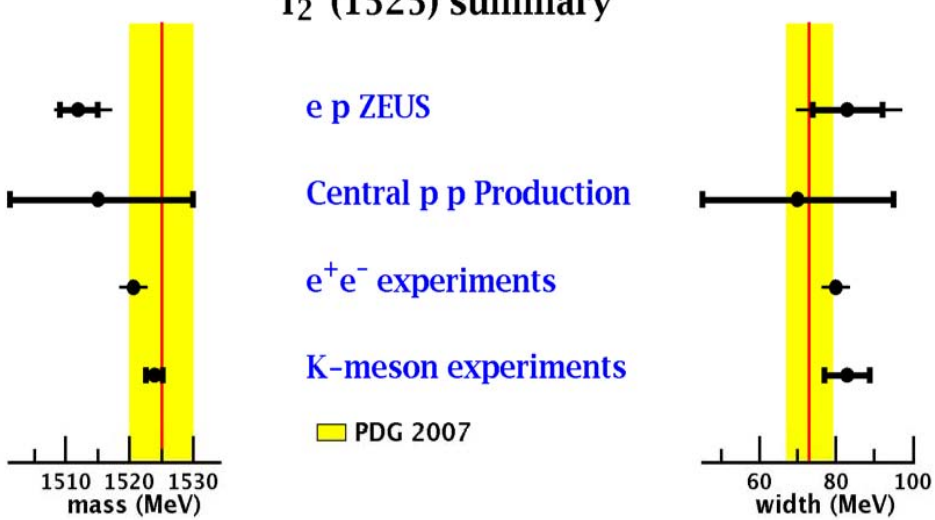
State $f_0(1710)$:

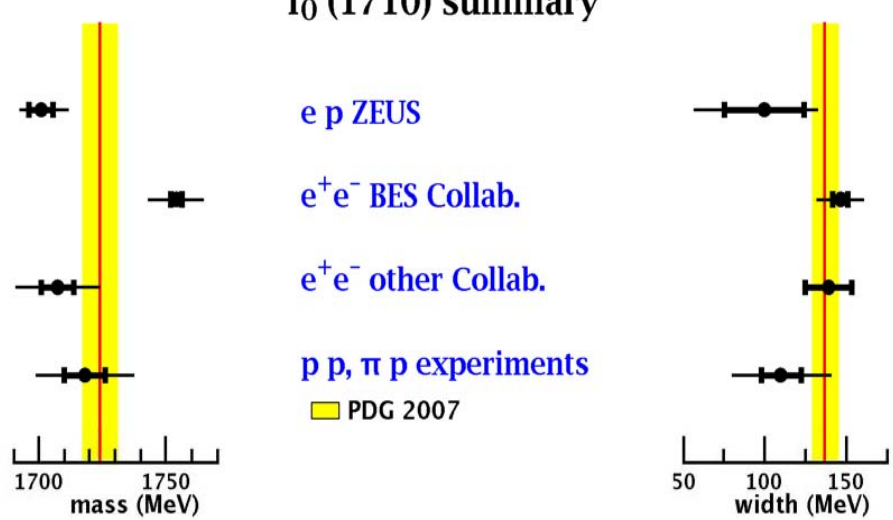
observed at 5σ significance

consistent with $J^{PC}=0^{++}$

glueball candidate

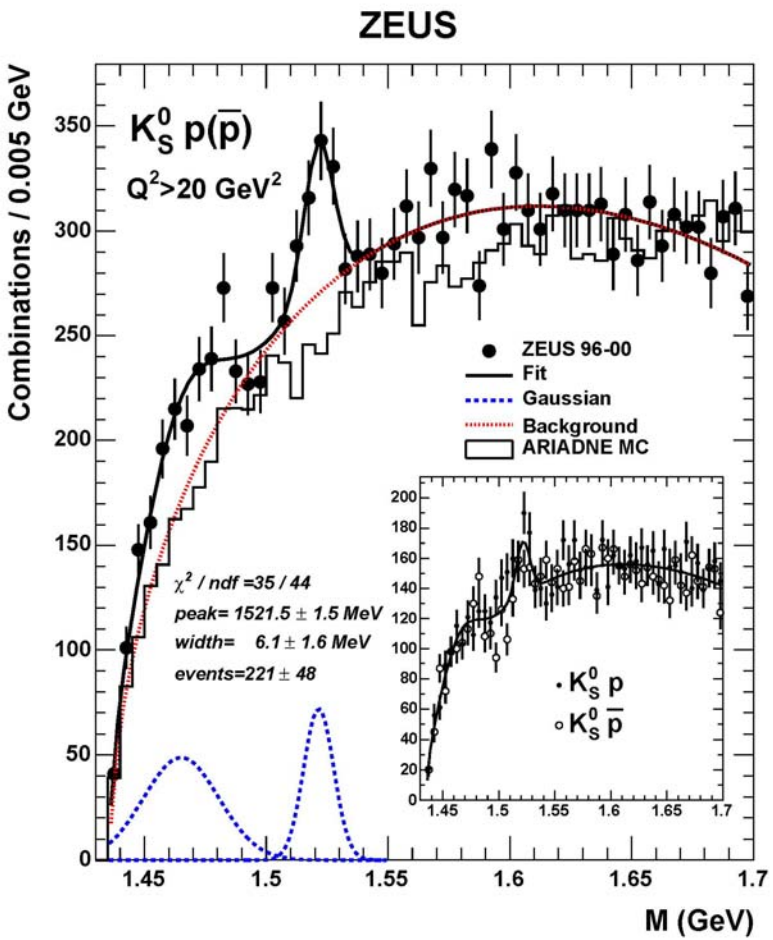
	Fit $\chi^2/ndf = 86/97$		PDG 2007 Values	
in MeV	Mass	Width	Mass	Width
$f_2(1270)$	1268 ± 10	176 ± 17	1275.4 ± 1.1	$185.2^{+3.1}_{-2.5}$
$a_2^0(1320)$	1257 ± 9	114 ± 14	1318.3 ± 0.6	107 ± 5
$f_2'(1525)$	$1512 \pm 3^{+2}_{-0.6}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1701 \pm 5^{+5}_{-3}$	$100 \pm 24^{+8}_{-19}$	1724 ± 7	137 ± 8





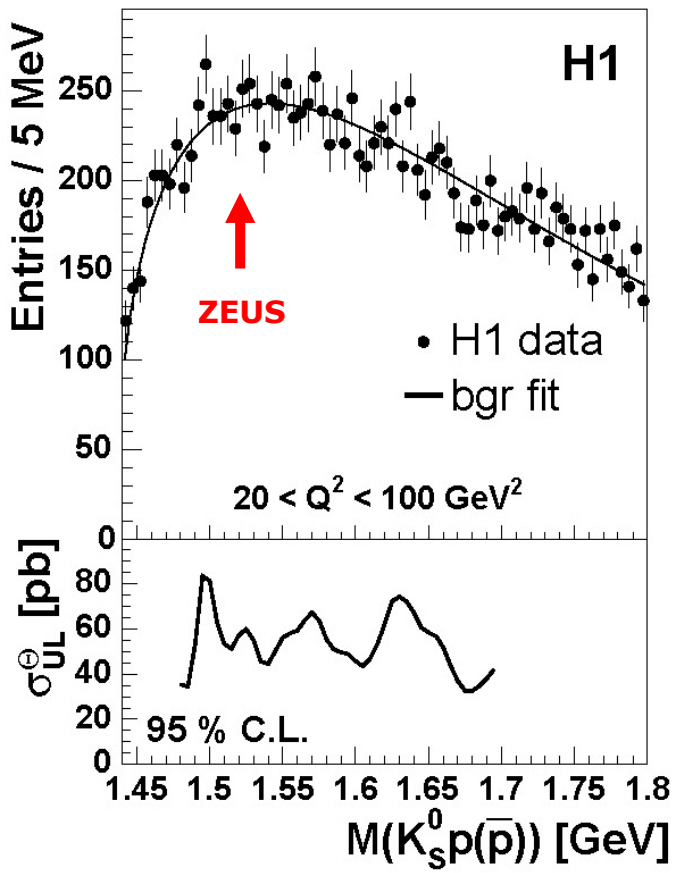
Strangeness States

Search for: $\Theta^+ \to K_s^0 p$ and $\overline{\Theta^+} \to K_s^0 \bar{p}$



ZEUS has a positive signal at 1522 MeV

HERA I data

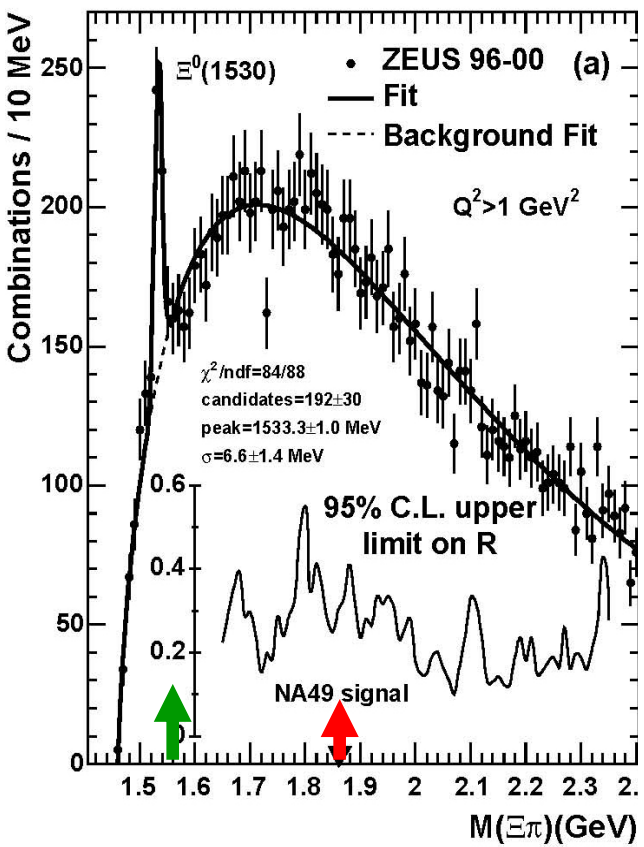


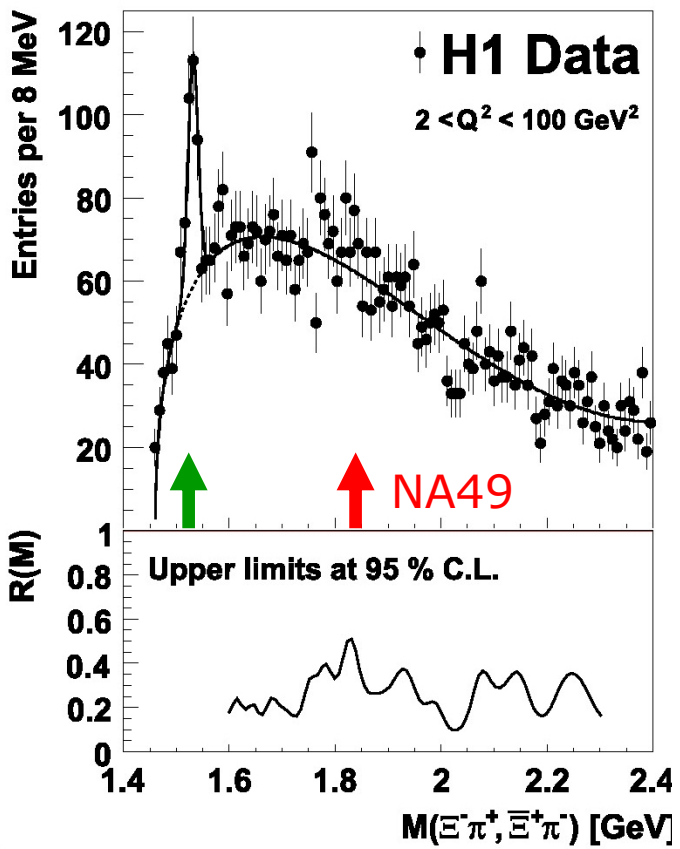
No signal observed in H1, upper limits set on cross sections.

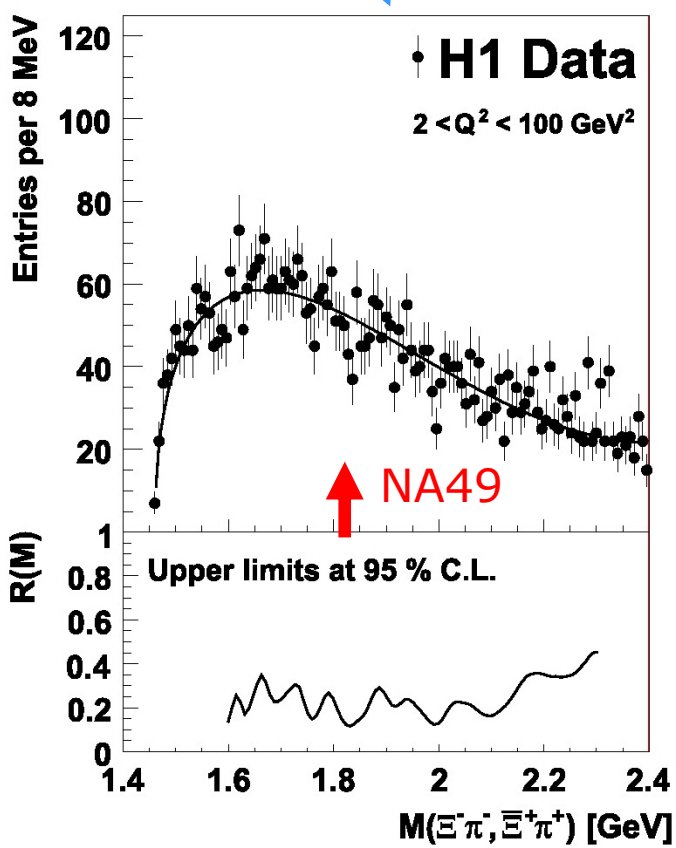
Strangeness States

Search for: Ξ^{--}_{5q} and Ξ^{0}_{5q}

$$\Xi^-\pi^- \to [\Lambda\pi^-]\pi^- \to [(p\pi^-)\pi^-]\pi^-$$
$$\Xi^-\pi^+ \to [\Lambda\pi^-]\pi^+ \to [(p\pi^-)\pi^-]\pi^+$$







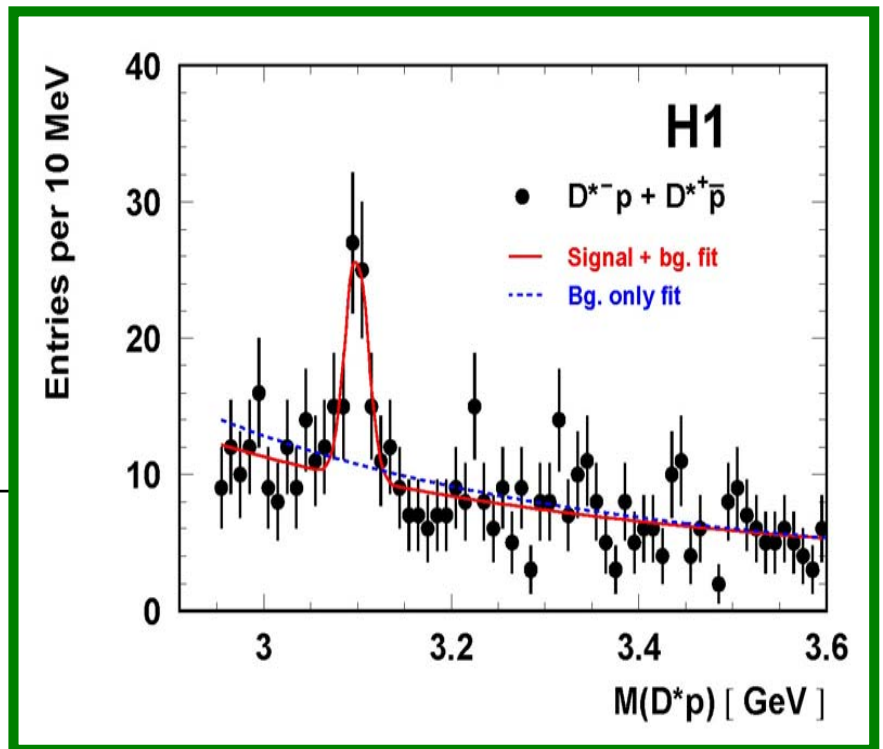
Known resonant state **Ξ(1530 MeV)⁰**. No signal at 1862 MeV (**NA49**), cross section upper limits set relative to 1530 state.

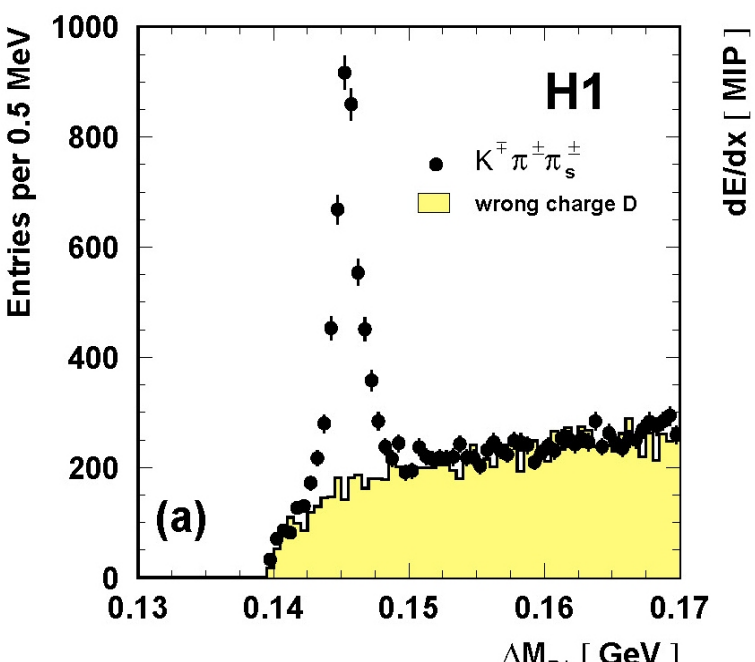
D*p Resonance (2004)

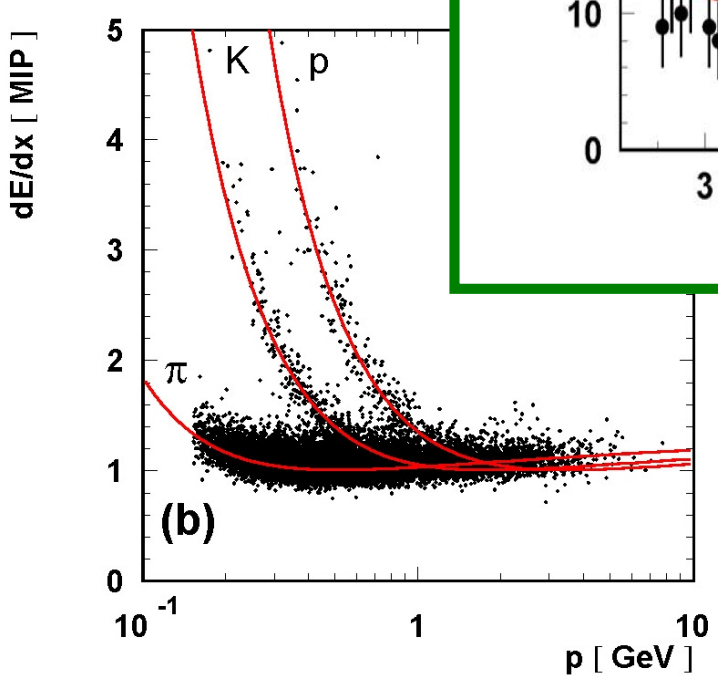
A resonance was observed by H1 with HERA I data (75 pb^{-1})

Invariant mass = 3099 ± 3 MeV

RMS = 12 ± 3 MeV







Minimum quark content:

$$uudd\bar{c}$$

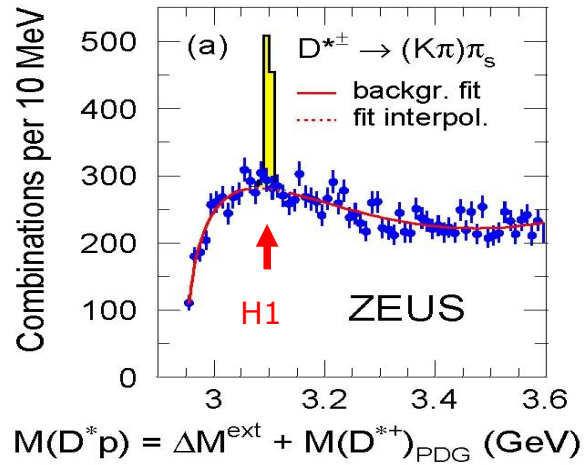
anti-charm baryon.

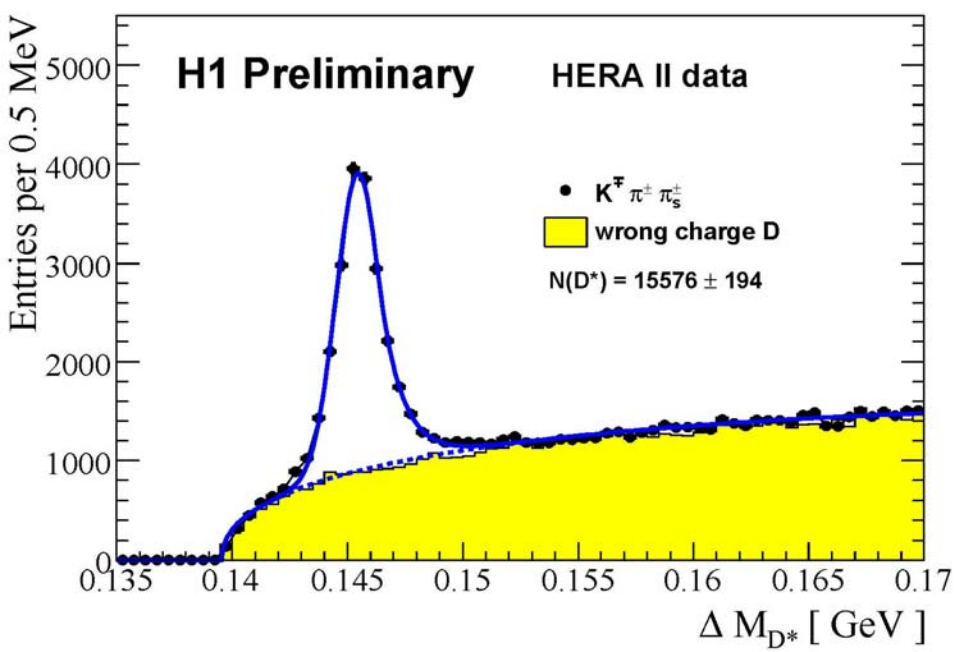
pentaquark candidate?

D*p Resonance (2008)

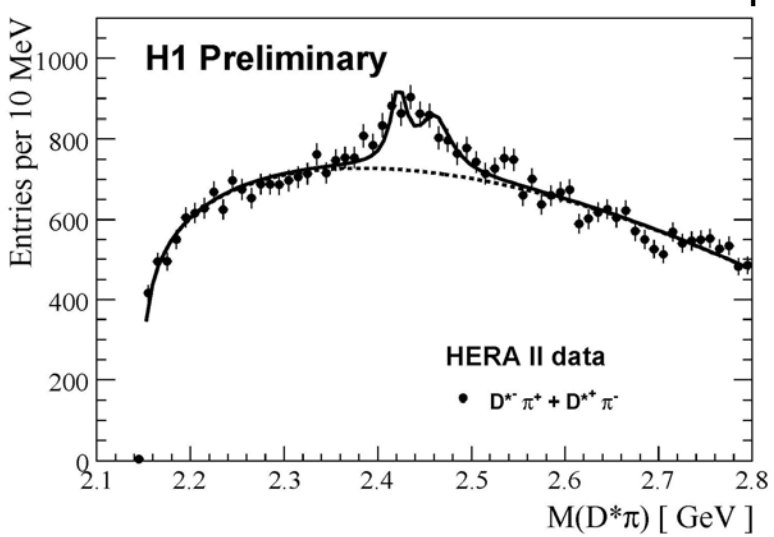
Excess not observed in other experiments (BaBar, CDF, ZEUS, ALEPH, FOCUS), therefore:

Repeat measurement with HERA II data (348 pb^{-1}) and nearly the same cuts: slightly reduced phase space.





Check for sensitivity by observing $D_1(2420)^0$ and $D_2^*(2460)^0 \to D^*\pi$: same D* selection and ΔM technique.

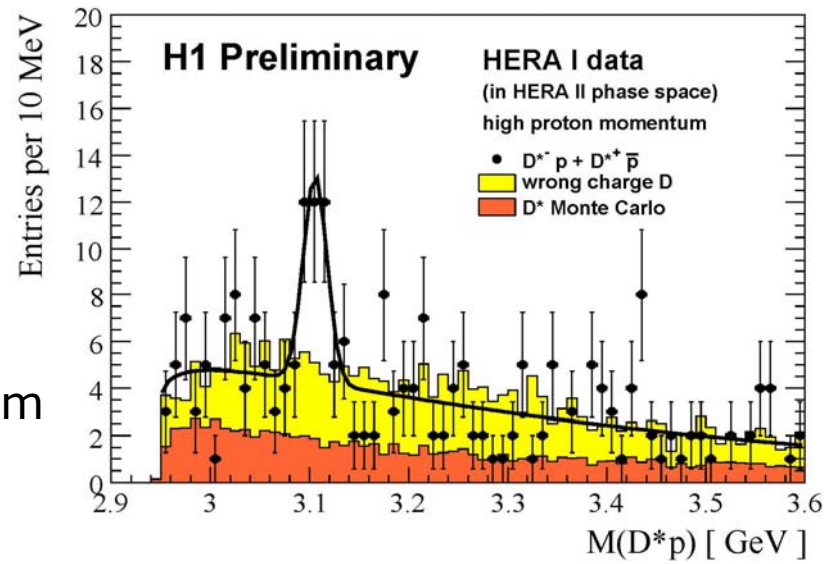


New Analysis

HERA I data

HERA II phase space

high proton momentum

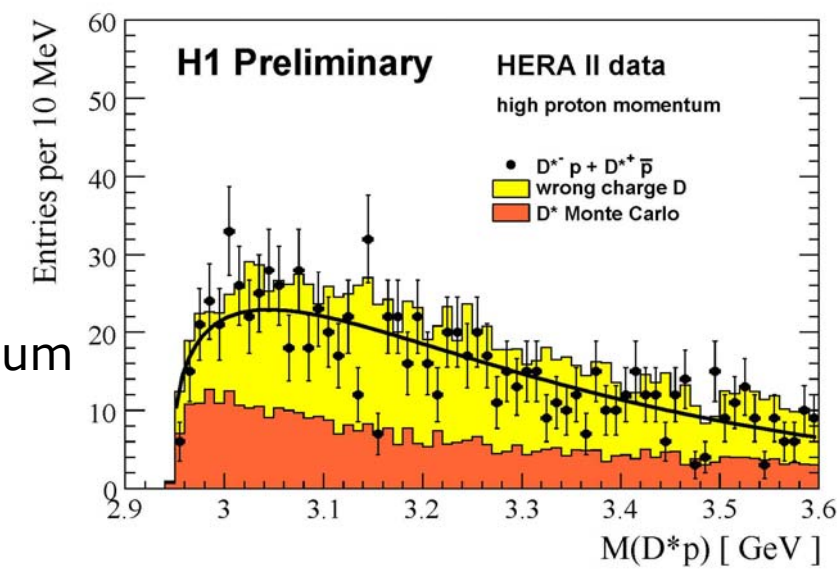


Signal observed in reduced phase space

ratio N(D*p)/N(D*) of 0.81±0.21%

HERA II data

high proton momentum



No peak, 95% CL limit of 16.3 events.

ratio limit: 0.10%

In both cases: D* Background well described (MC+wrong charge)

Summary

- 23 years since conception and after 15 years of operation, **HERA** stopped on June 30th, 2007. An integrated luminosity of 1 fb^{-1} was taken by both experiments **H1** and **ZEUS** combined.
- **ZEUS** and **H1** have ongoing spectroscopy programs, from light quarks to beauty and for multi-parton resonant state searches.
- **HERA II** statistics are now being exploited to understand the properties of the investigated states.
- No positive signal observed in the most recent pentaquark searches.

The End of an Hera

Excited Charm Mesons

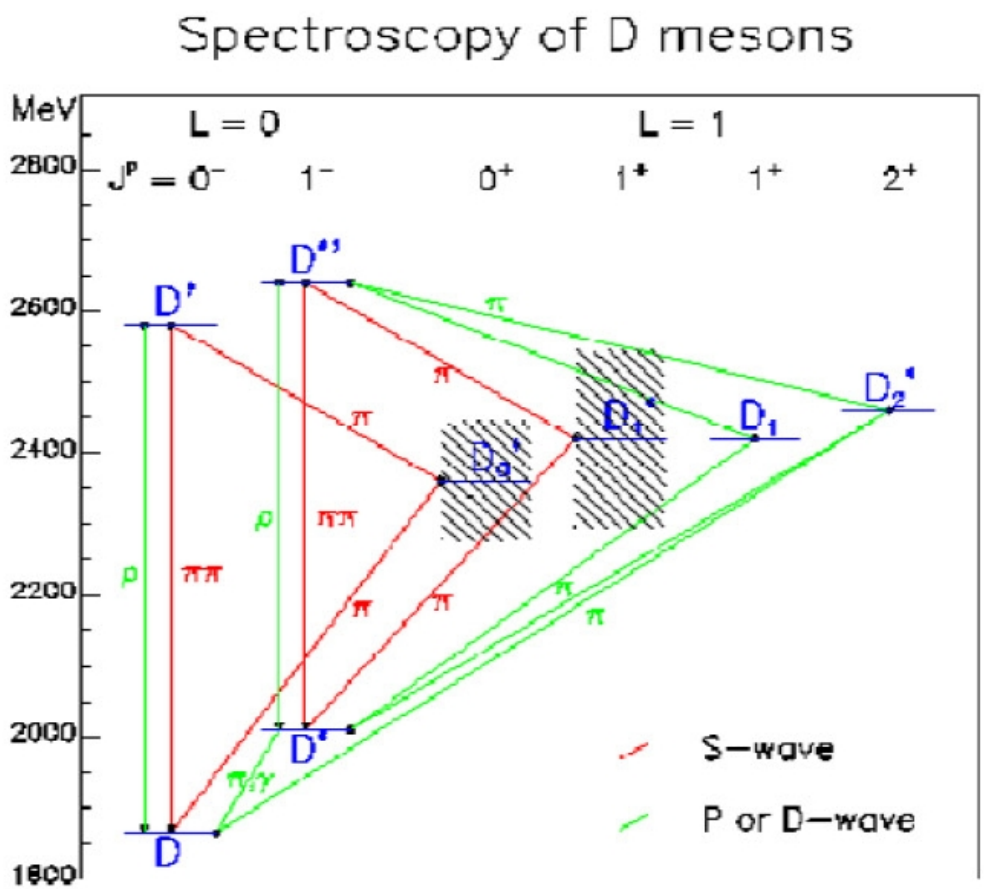
ZEUS:

$D_1(2420)^0, D_2(2460)^0 \rightarrow D^{*+}\pi_a^-$

$D_2(2460) \rightarrow D^+\pi_a^-$

$D_{s1}^+(2536) \rightarrow D^{*+}K^0_s$

$D_{s1}^+(2536) \rightarrow D^0K^+$



measure masses, widths, fragmentation functions, helicity dependence, ..

"Backward Analysis"

Study D* mass in the signal region and in side bands:

Excess is observed only for the signal region with HERA I: the sample is charm enriched.