Hadron Spectroscopy and Heavy Flavor Production at HERA

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on behalf of the H1 and ZEUS Collaborations

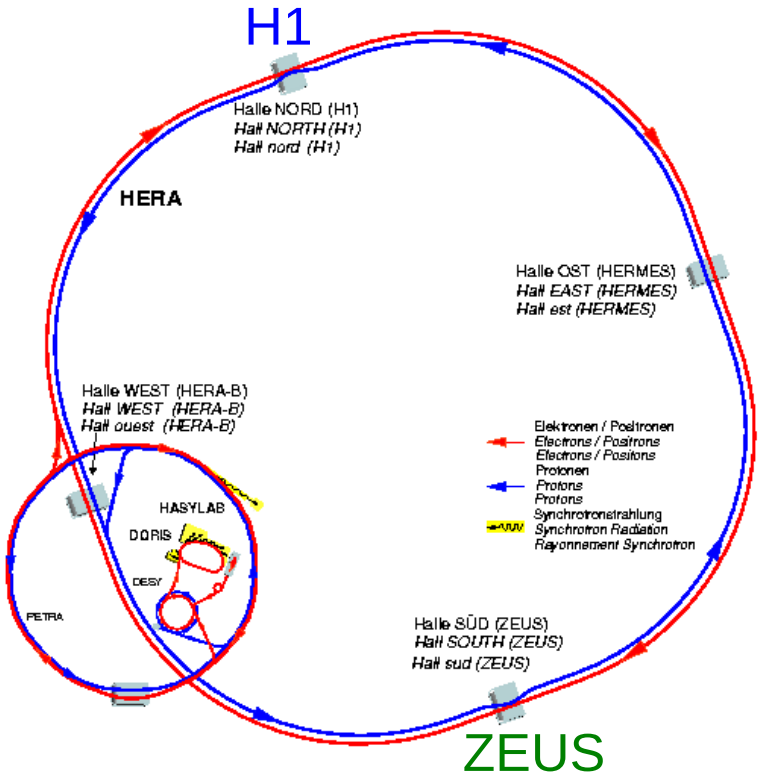
- Recent results on charm and beauty production
- Results on search for pentaquarks

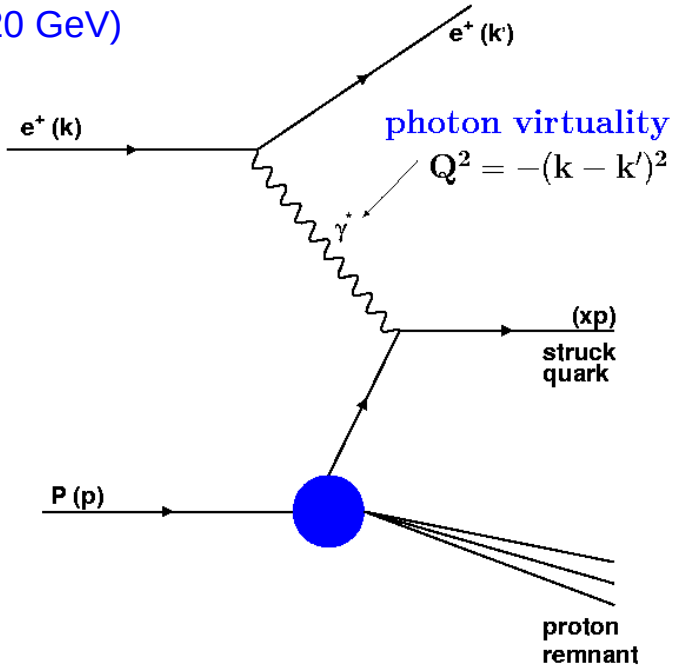
19th Rencontres de Physique de la Vallee d'Aoste
La Thuile 2005, 27th February- 5th March

The HERA collider

$e^{\pm}$ 27.5 GeV

p 920 GeV (820 GeV)





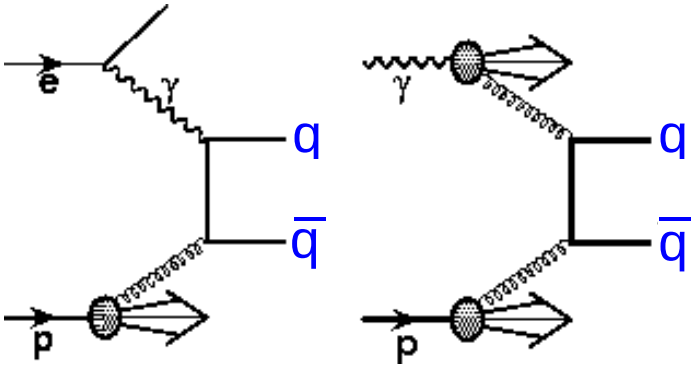
Q^2: 4-momentum transfer squared

x : Bjorken-x scaling variable

Year	Beams	$s^{½}$ (GeV)	Luminosity (pb^{-1}) ZEUS - H1
94-97	e^+p	300	47.7 - 35.6
98-99	e^-p	318	16.7 - 16.4
99-00	e^+p	318	65.1 - 65.2

Heavy flavor production at HERA

HFL production processes at HERA:



direct resolved

Two kinematic regimes:

deep inelastic scattering ($Q^2 > 1 GeV^2$) dominated by direct process

photoproduction ($Q^2 \sim 0 GeV^2$) resolved contribution important

Powerful tool for testing proton structure and pQCD

NLO QCD calculations available:

FMNR (Frixione, Mangano, Nason, Ridolfi) in photoproduction

HVQDIS (Harris, Smith) in deep inelastic scattering

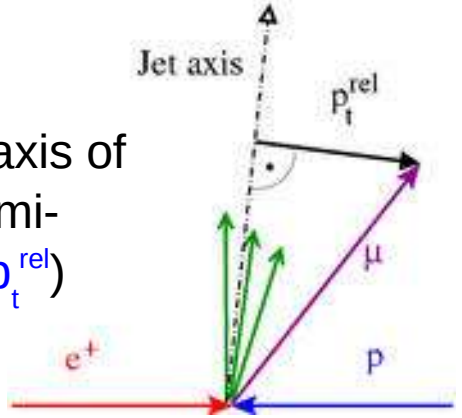
Heavy Flavor tagging

Charm: efficiently tagged via reconstruction of the D^* decay

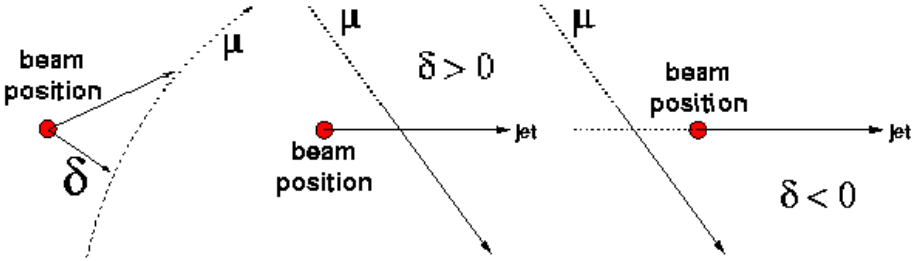
$D^{*\pm} \rightarrow D^0\pi^{\pm}_s \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}_s$ and mass difference $\Delta M = M(K\pi\pi) - M(K\pi)$

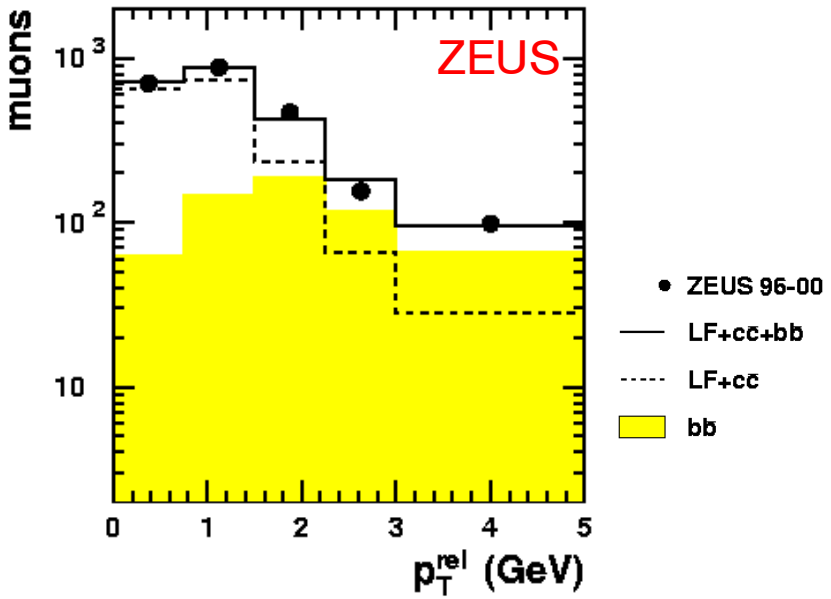
Beauty: high mass and long lifetime of B-hadrons can be exploited to discriminate b production from that of lighter quarks (true for charm to less extent)

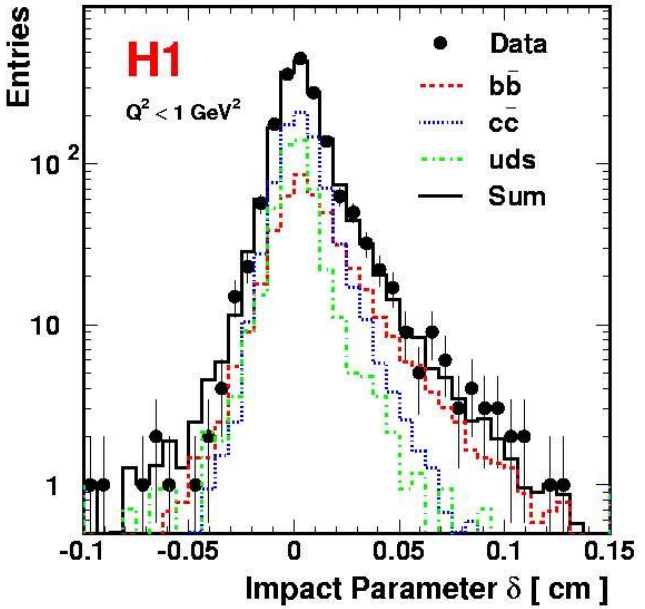
pt relative to jet axis of lepton from b semi-leptonic decay (p_t^{rel})



signed impact parameter (δ) of tracks from b decay





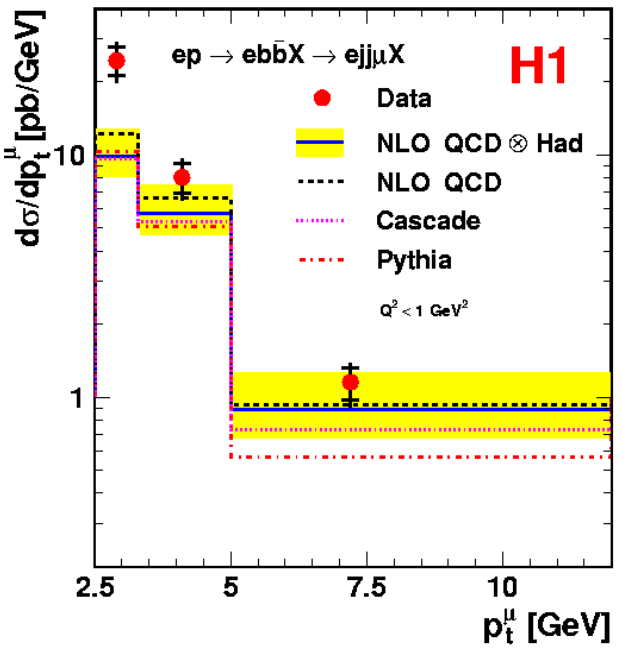


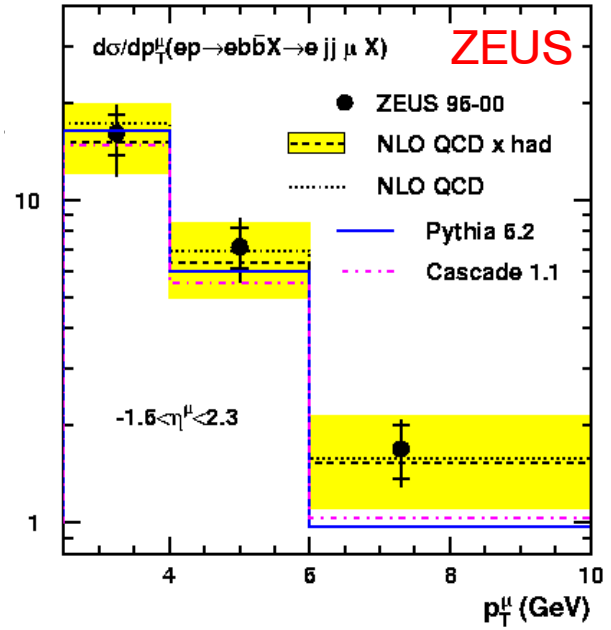
Beauty cross sections

H1: p_t^{rel}, δ

ZEUS: p_t^{rel}

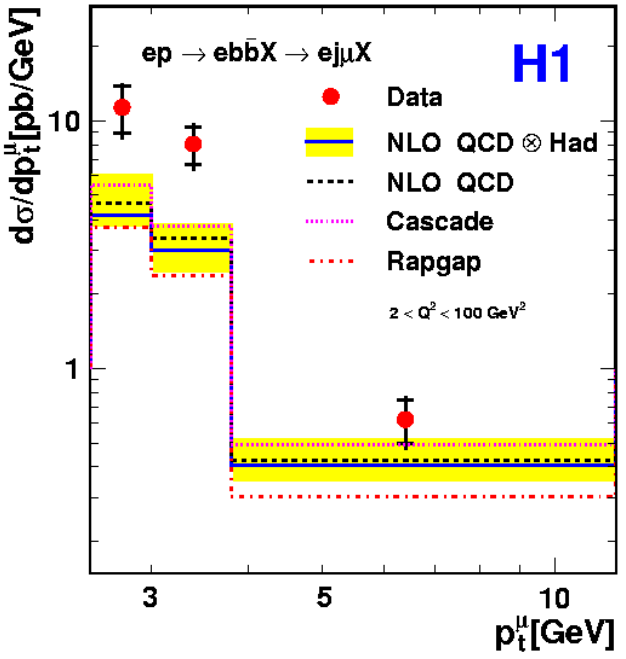
photoproduction ⇒

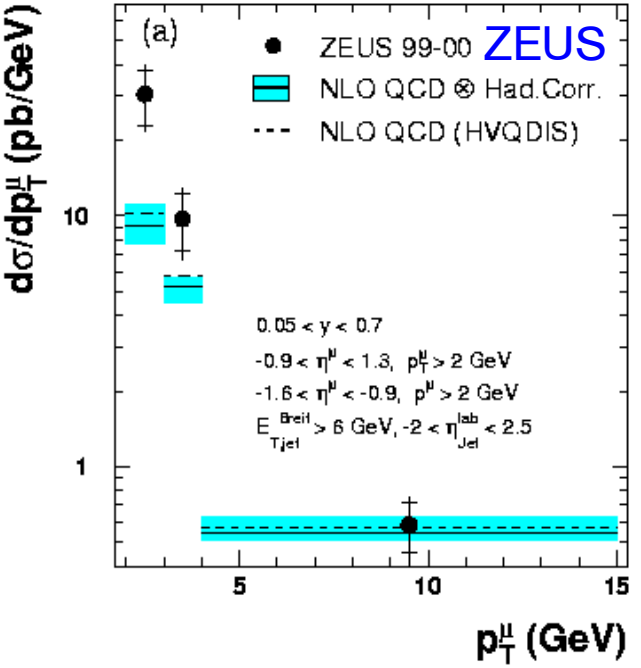




Better agreement for ZEUS data

DIS ⇒

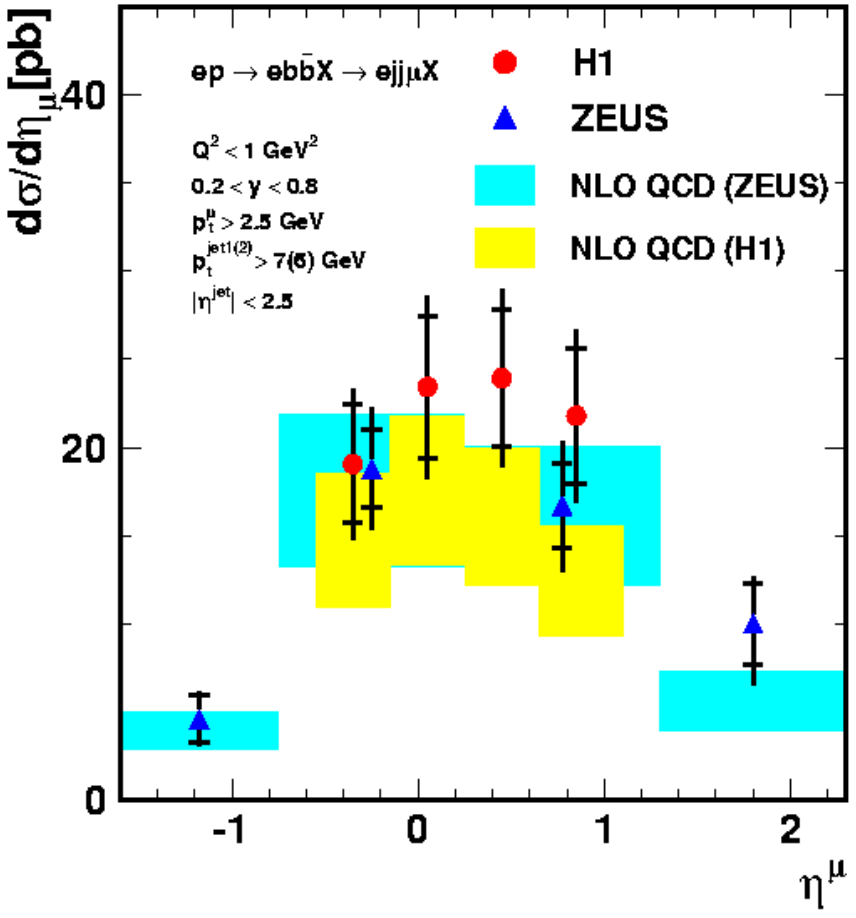




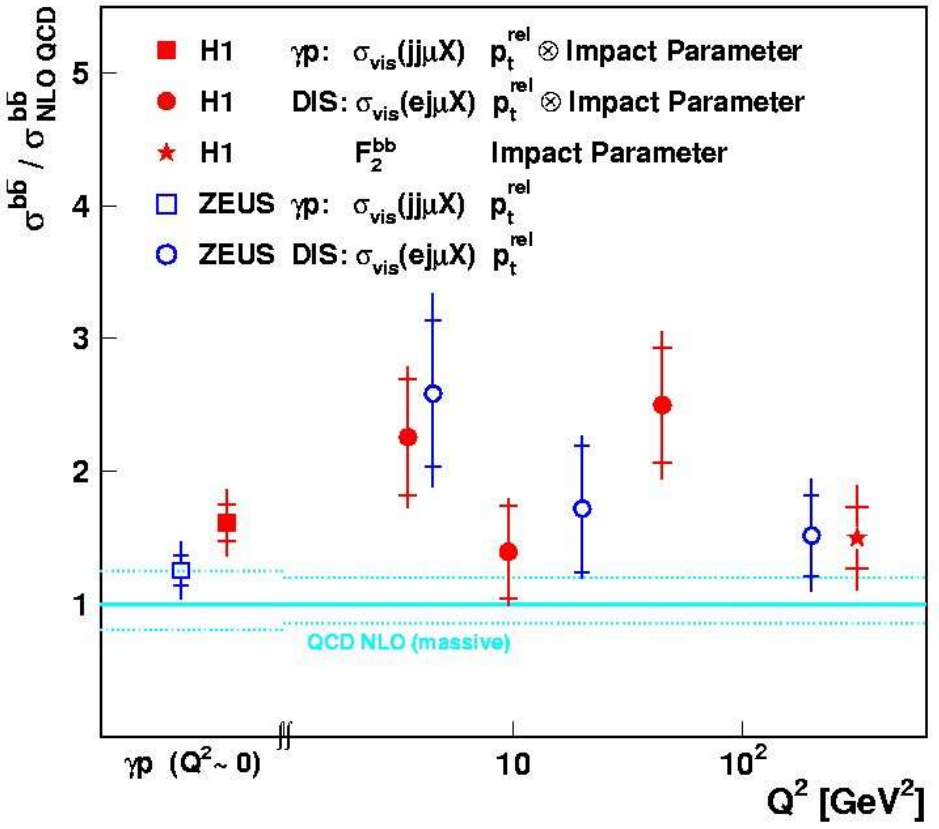
Both experiments overshooting theory at low p_t

Beauty cross sections

$Q^2 < 1 GeV^2$



Data/theory vs Q^2



Data tendency to be above the NLO QCD predictions

General agreement between H1 and ZEUS

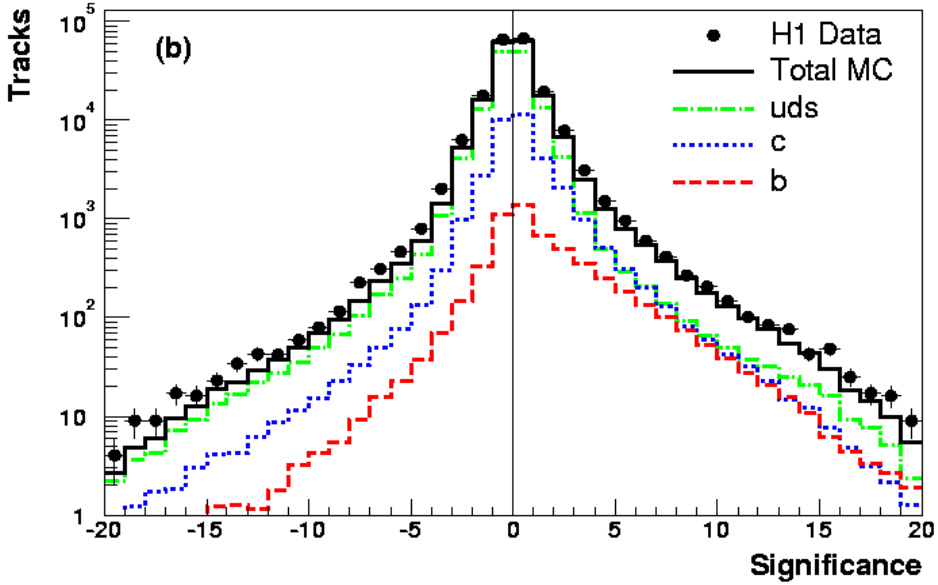
H1: hep-ex/0502010

ZEUS: Phys. Lett. B599 (2004) 173-189
Phys. Rev. D70 (2004) 012008

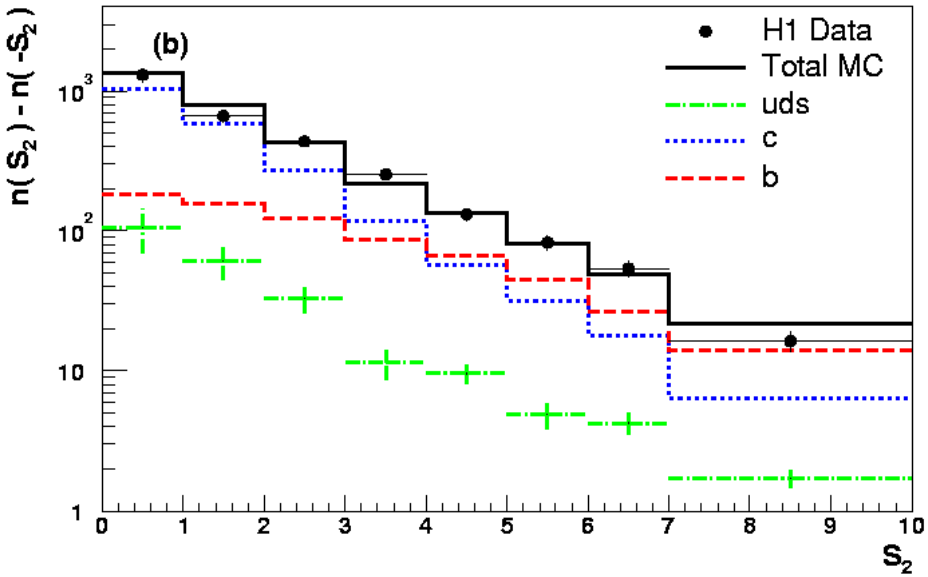
Inclusive lifetime tagging for charm and beauty

$Q^2>150\ GeV^2$
$0.1< y < 0.7$

- Quark flavor separation using significance: $S = \delta / \sigma(\delta)$

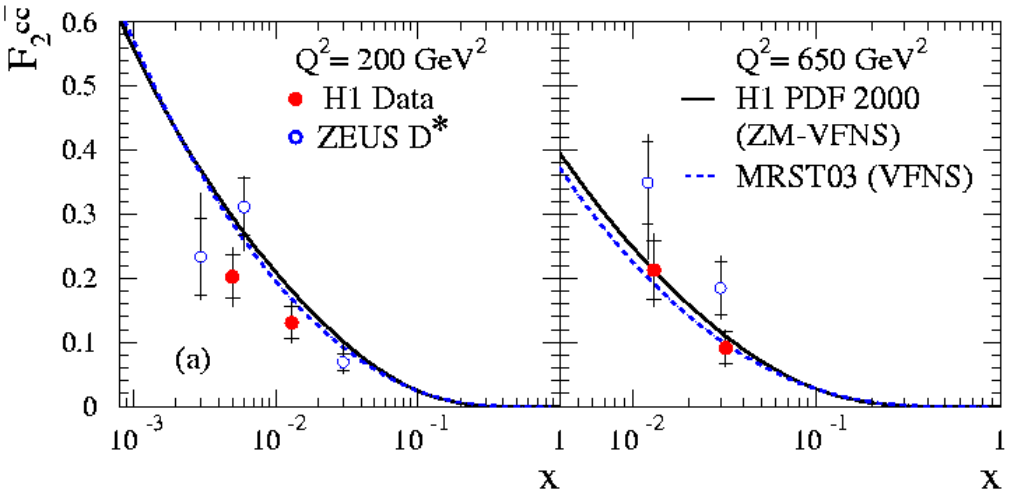


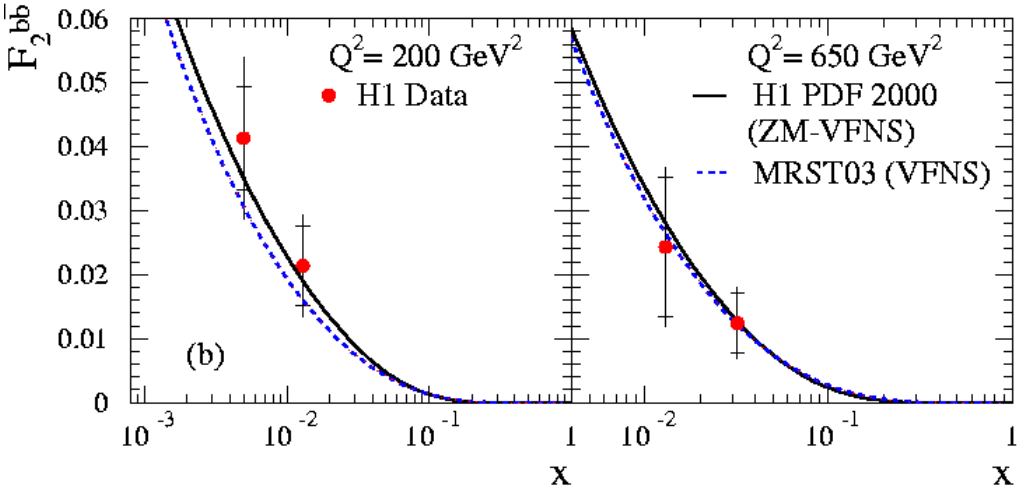
- Remove negative from positive side of distribution
  and fit to extract *c* and *b* fractions

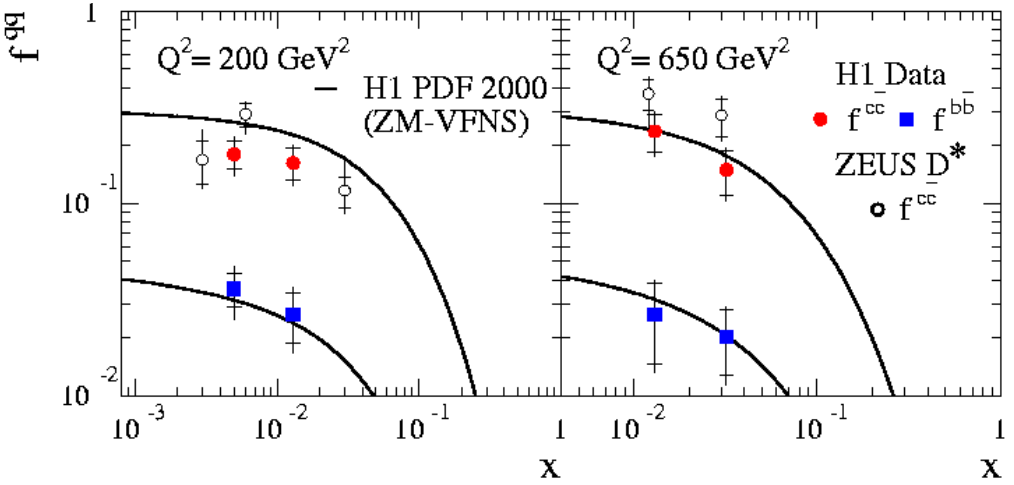


F_2^{cc} and F_2^{bb} measurement at high Q^2

H1: extraction of fully inclusive cross sections
(ZEUS points extracted from D^*)







Agreement between experiments and with NLO QCD

First measurement of F_2^{bb}

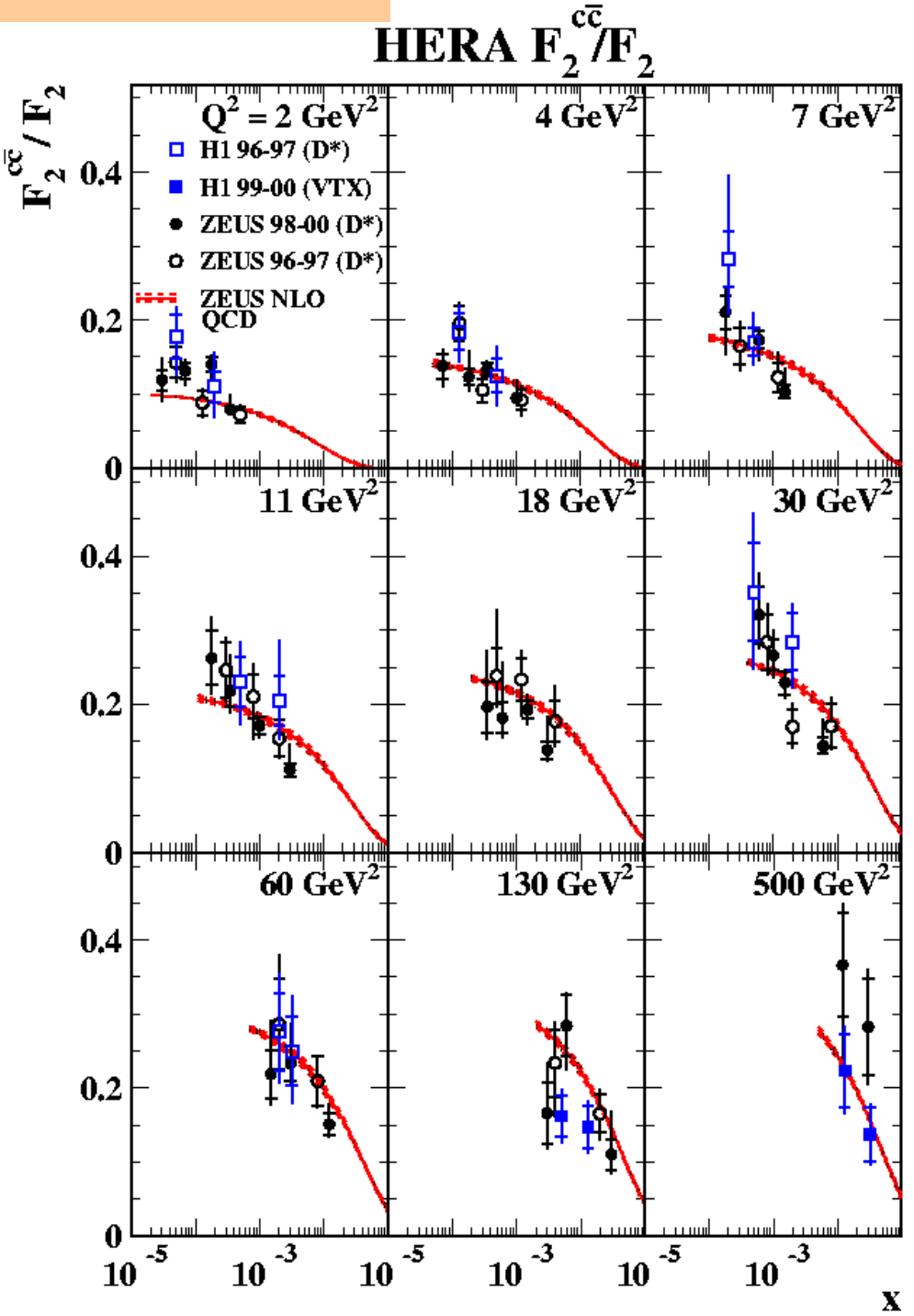
DESY 04-209

F_2^{cc}/F_2 vs x in Q^2 bins

contribution of charm to F_2

rises with Q^2 from 10 to 30%

H1 and ZEUS data in agreement and consistent with NLO QCD

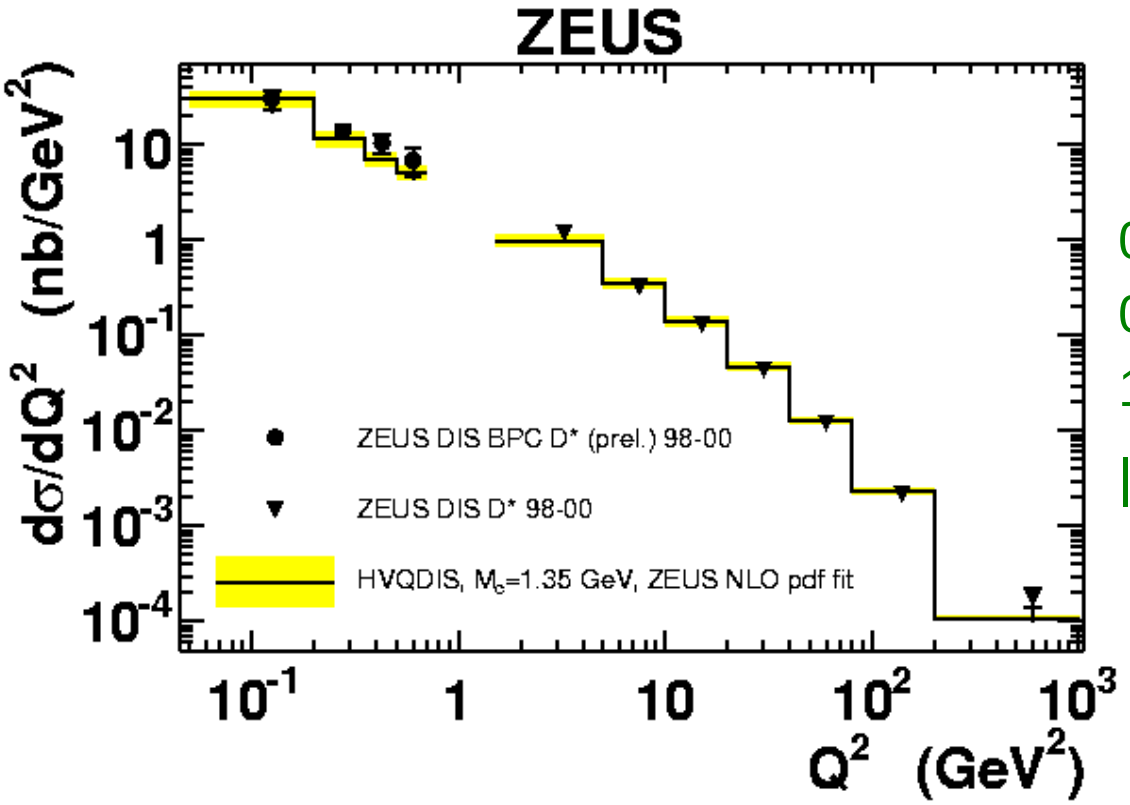


D^* cross section at low Q^2

Test of NLO QCD for charm production in region of transition to photoproduction regime

Low Q^2 values reached by measuring the scattered electron in Beam-Pipe Calorimeter (BPC)

preliminary



$0.05 < Q^2 < 0.7$ GeV^2

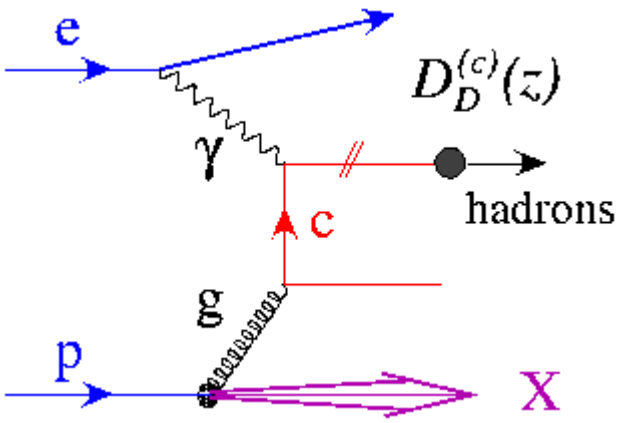
$0.02 < y < 0.85$

$1.5 < p_T(D^*) < 9.0$ GeV

$|\eta(D^*)| < 1.5$

Measurements consistent with predictions even at low Q^2

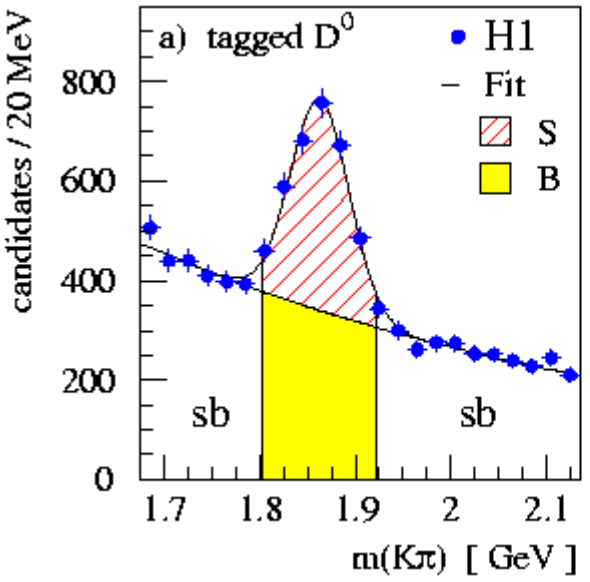
D-meson production



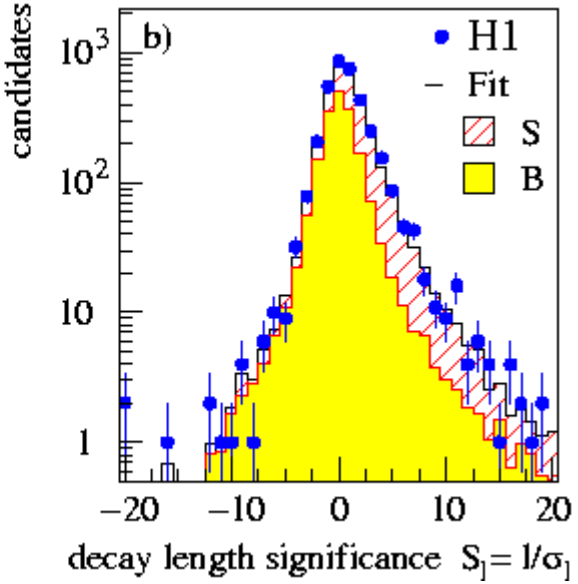
Study of fragmentation using D-meson production

Charm tagging via reconstruction of secondary vertex with the H1 central silicon tracker (CST)

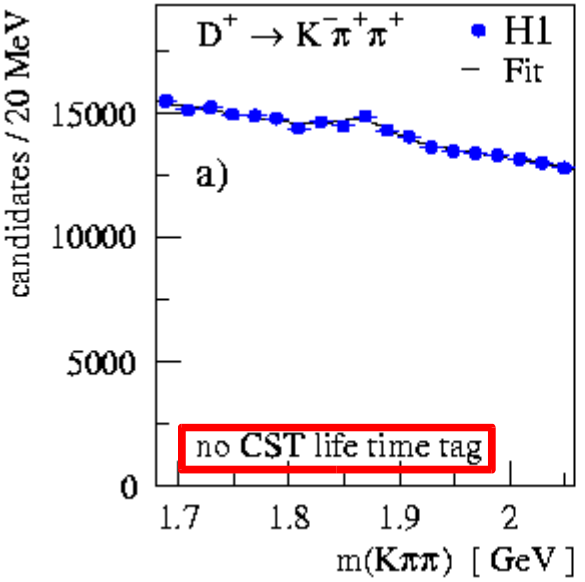
Check of CST response

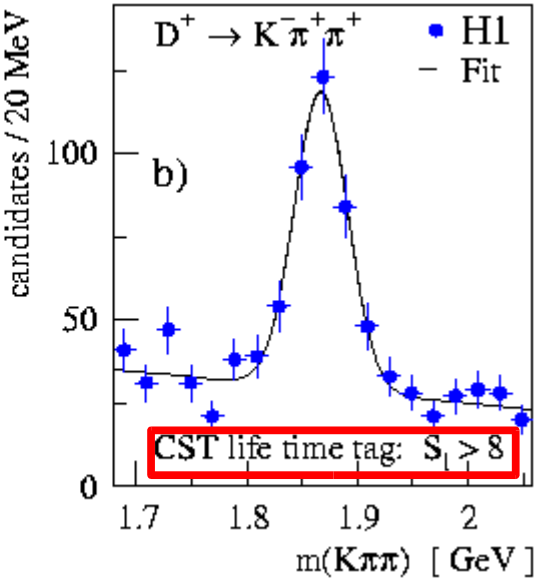


D^0 from D^* reconstruction

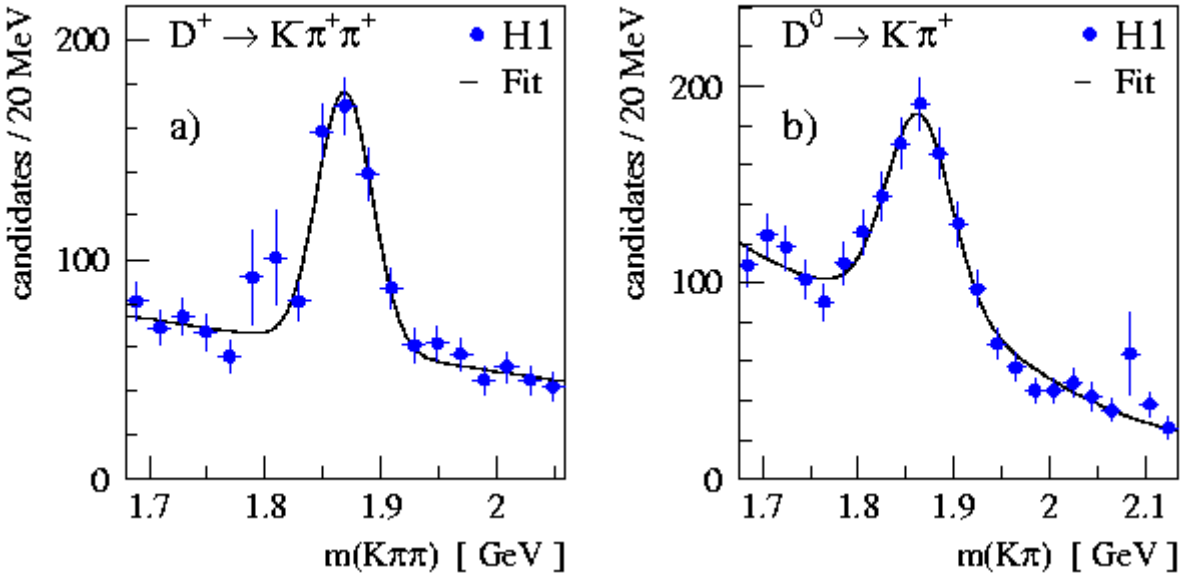


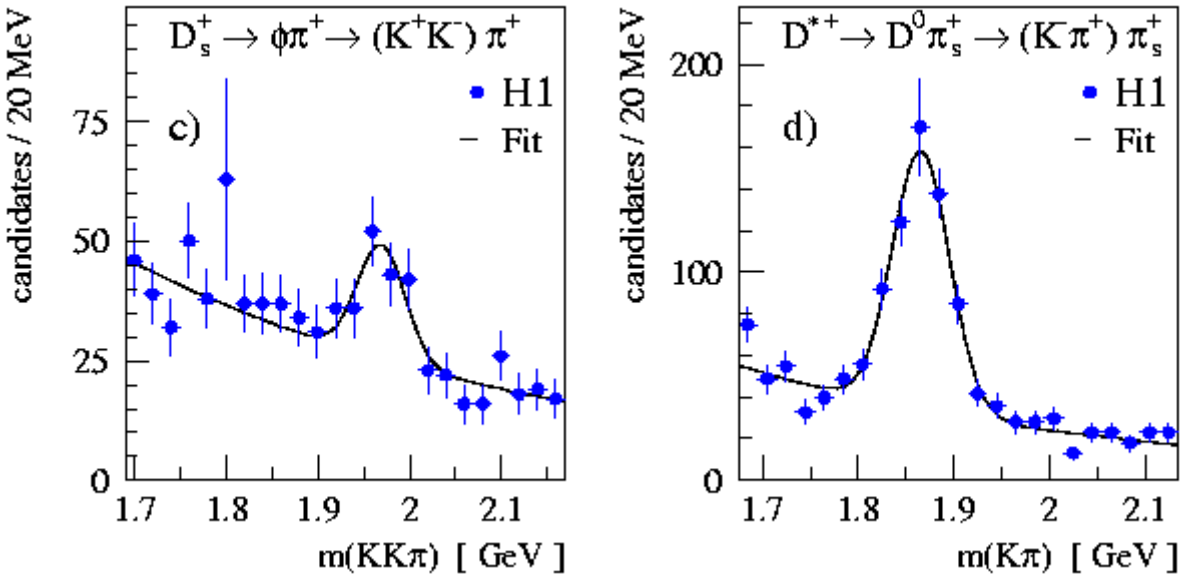
S from MC, B from data





D-meson production





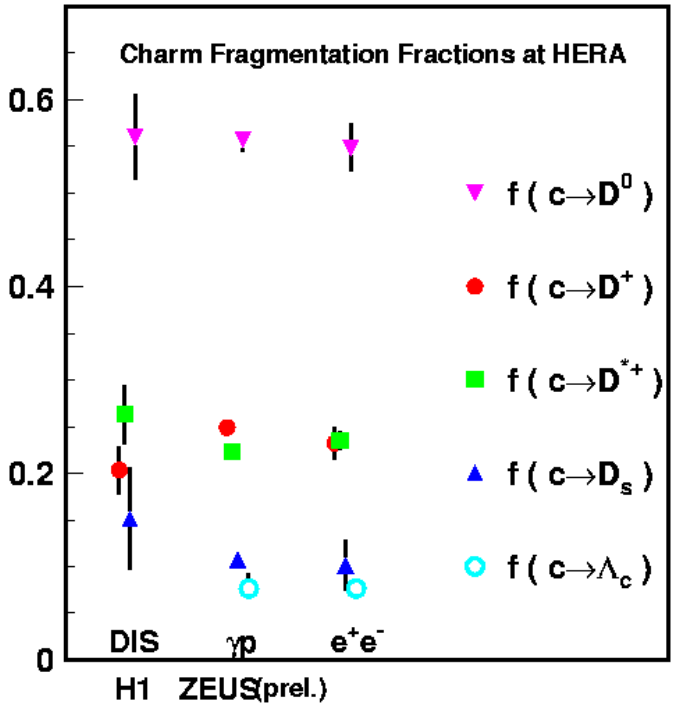
Fit:

gaussian + appropriate bkg

signal mass and width
are free parameters

Determine cross sections and compare to MC to deduce fragmentation factors

D-meson production



hep-ex/0408149

Fragmentation factors in good agreement with LEP

$1.5 < Q^2 < 1000\ \text{GeV}^2$, $0.02 < y < 0.7$, $p_T(D) > 3.0$ GeV, $|\eta(D)| < 1.6$

		ZEUS (nb)	NLO QCD (nb)
$(e^{\pm}p$	$e^{\pm}D^0X)$	$7.44 \pm 0.78\,^{+0.29}_{-0.49}$	7.14
$(e^{+}p$	$e^{+}D^{\pm}X)$	$2.42 \pm 0.30\,^{+0.21}_{-0.06}$	3.02
$(e^{\pm}p$	$e^{\pm}D_sX)$	$2.25 \pm 0.30\,^{+0.09}_{-0.33}$	1.32
$(e^{\pm}p$	$e^{\pm}D^*X)$	$3.22 \pm 0.08\,^{+0.07}_{-0.05}$	3.06

preliminary

Good agreement for D^* and D^0, some deviation for D_s

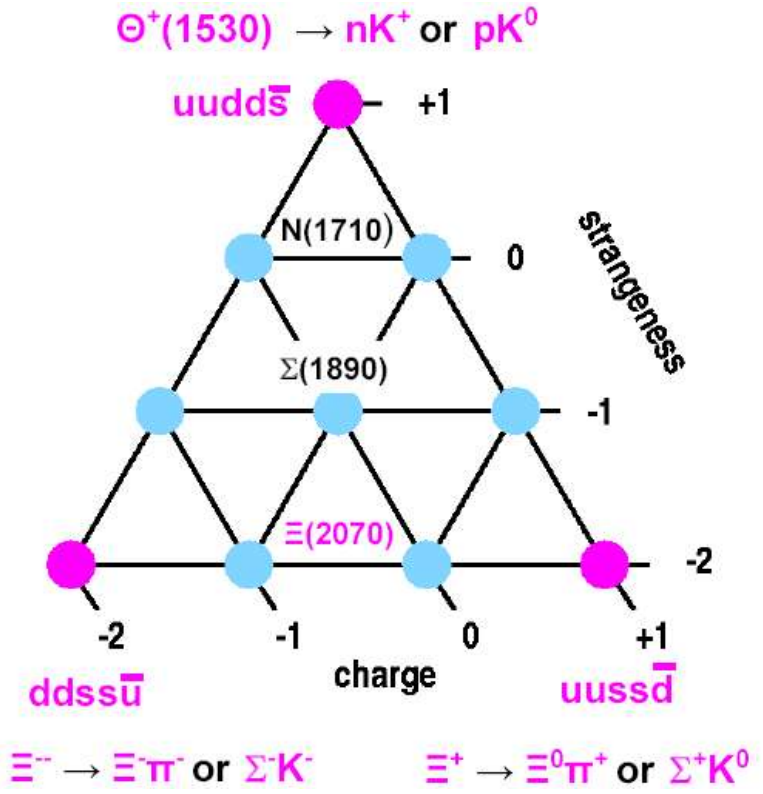
Search for pentaquarks at HERA

- Several experiments reported observation of a narrow resonance with a mass of ~1530 MeV decaying to K^+n or $K^0_s p$

  State with B = +1 and S = +1 $\Rightarrow$ minimal quark composition $uudd\bar{s}$

- Furthermore, NA49 reported observation of Ξ^{--} and Ξ^0, states with S = −2

Predicted in 1997 by
Diakonov, Petrov, Polyakov



ZEUS search for $\Theta^{+(--)} \rightarrow \overline{(p)} K^0_s$

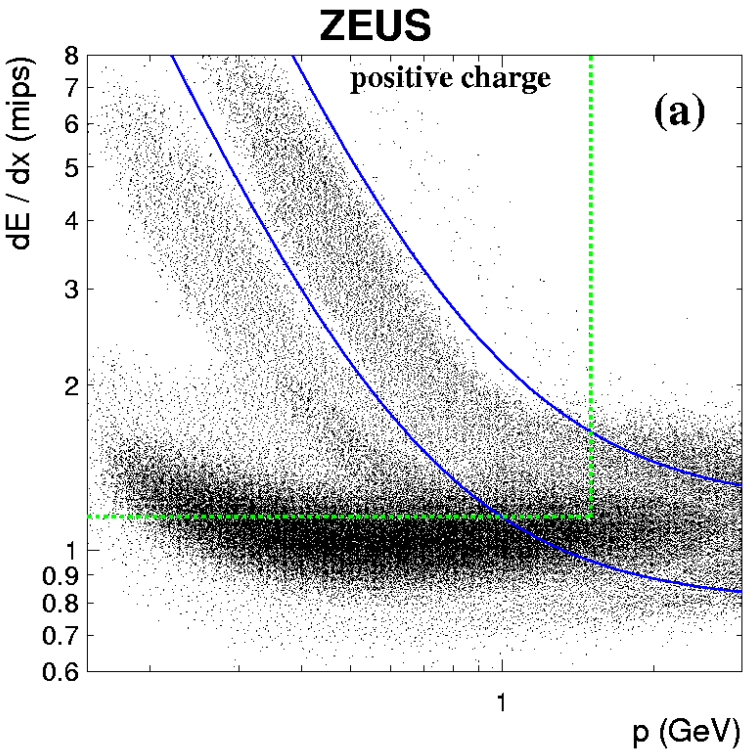
$L = 121\ pb^{-1}$

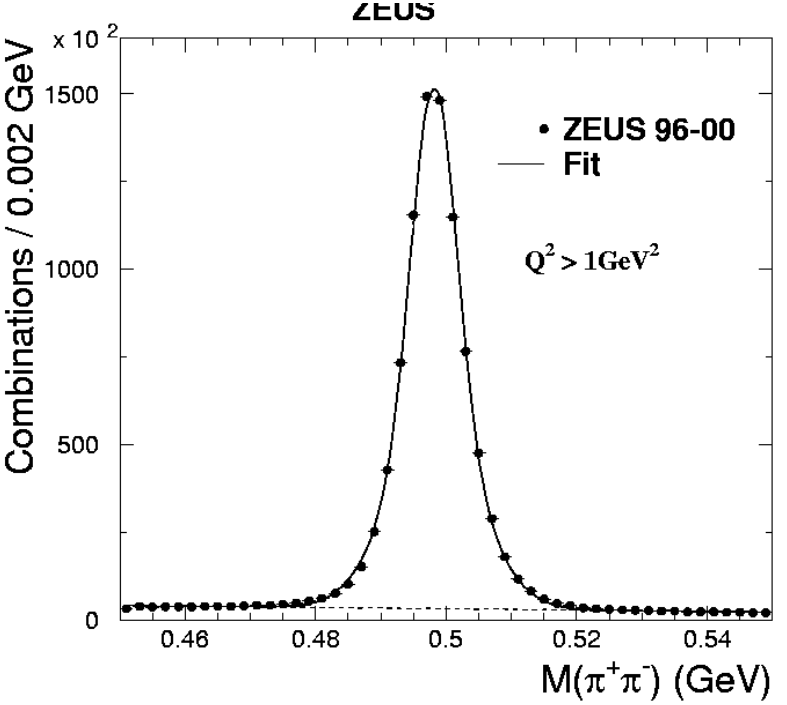
proton selection:

- dE/dx > 1.15 mips
- p(p) < 1.5 GeV
- $|\eta|<1.75$
- proton purity of ~60%

$870000\ K^0_s$:

- $p_T(K^0)>0.3$ GeV
- $|\eta|<1.5$
- mass peak at 498.12±1
- background < 6%





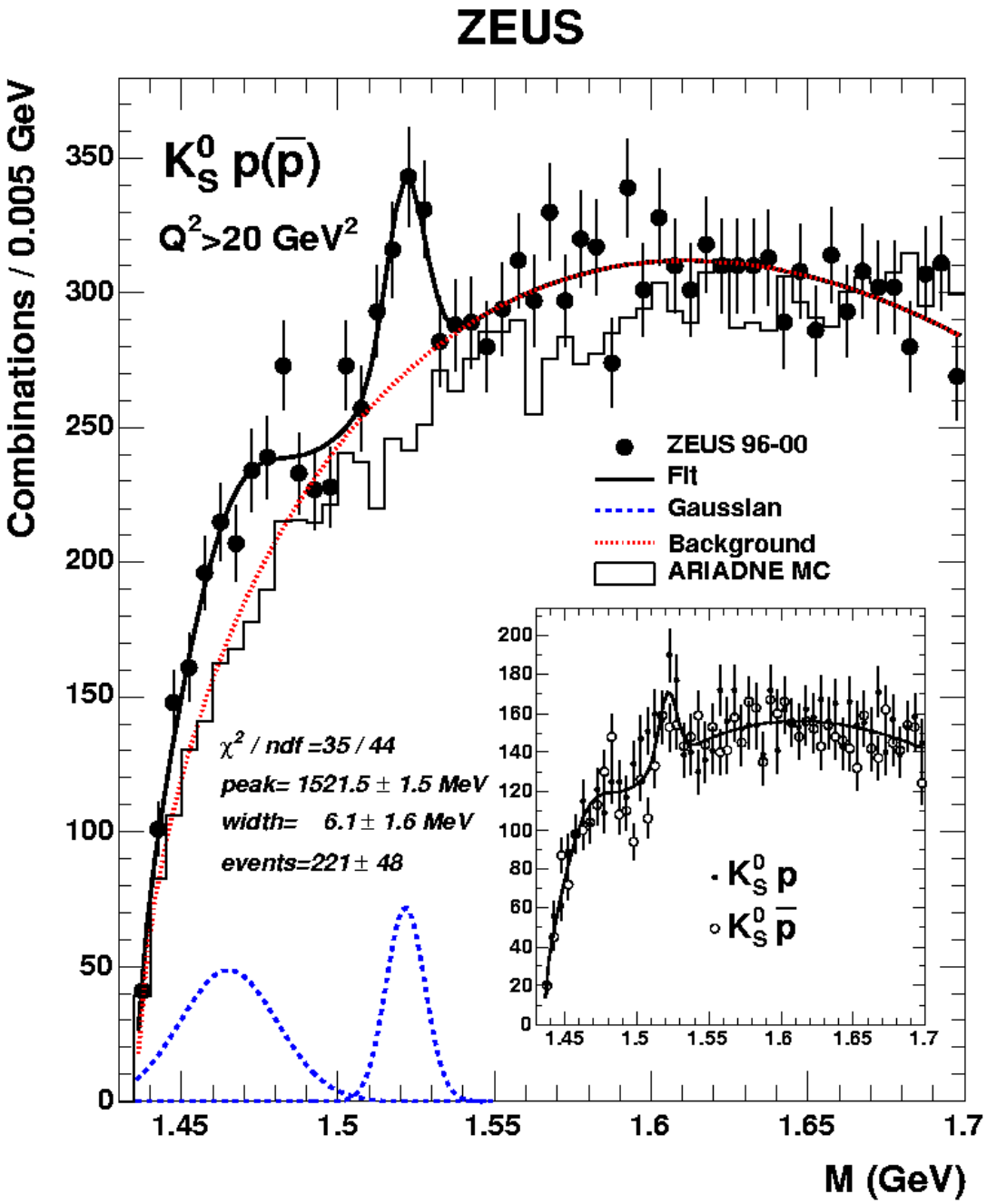
ZEUS search for $\Theta^{+(--)} \rightarrow \overset{(-)}{p} K^0_S$

Bump best seen for $Q^2>20 GeV^2$

Fitting with bkg + two gaussians
- M=1522 MeV
- N=221±48
- ⇒ 4.6σ bump

Not shown:
fitting with bkg + gaussian
- ⇒ 3.9σ bump

Signal seen in both charges
Inset: K^0_S anti-p 96±34 events



Phys. Lett. B591 (2004) 7-22

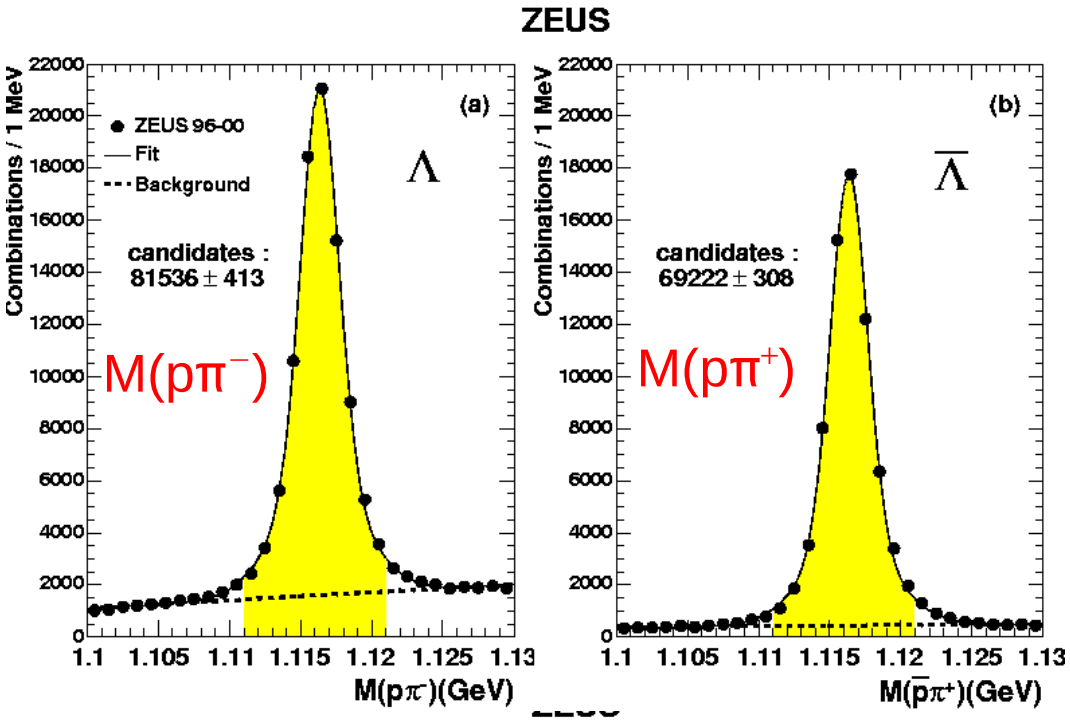
ZEUS search for PQ decaying to $\Xi^-\pi^\pm$

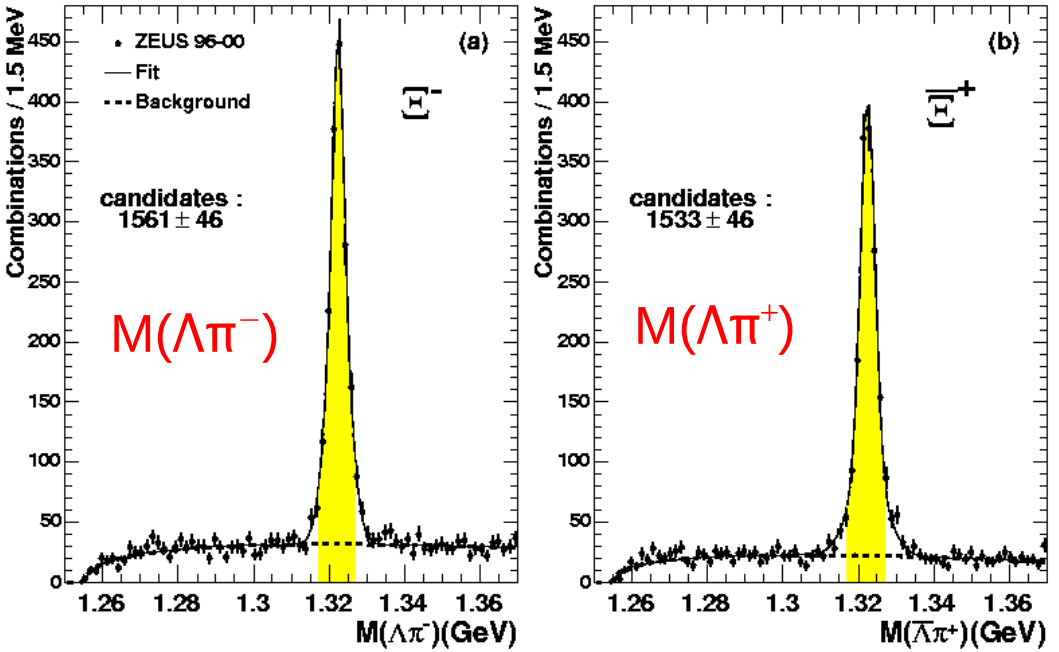
$\Xi^{--} \rightarrow \Xi^-\pi^\pm$
$\hookrightarrow \Lambda\pi^-$
$\hookrightarrow p\pi^-$

$L = 105 pb^{-1}$
$Q^2 > 1\ GeV^2$

track quality cuts:
$p_T > 0.150$ GeV
$|\eta| < 1.75$

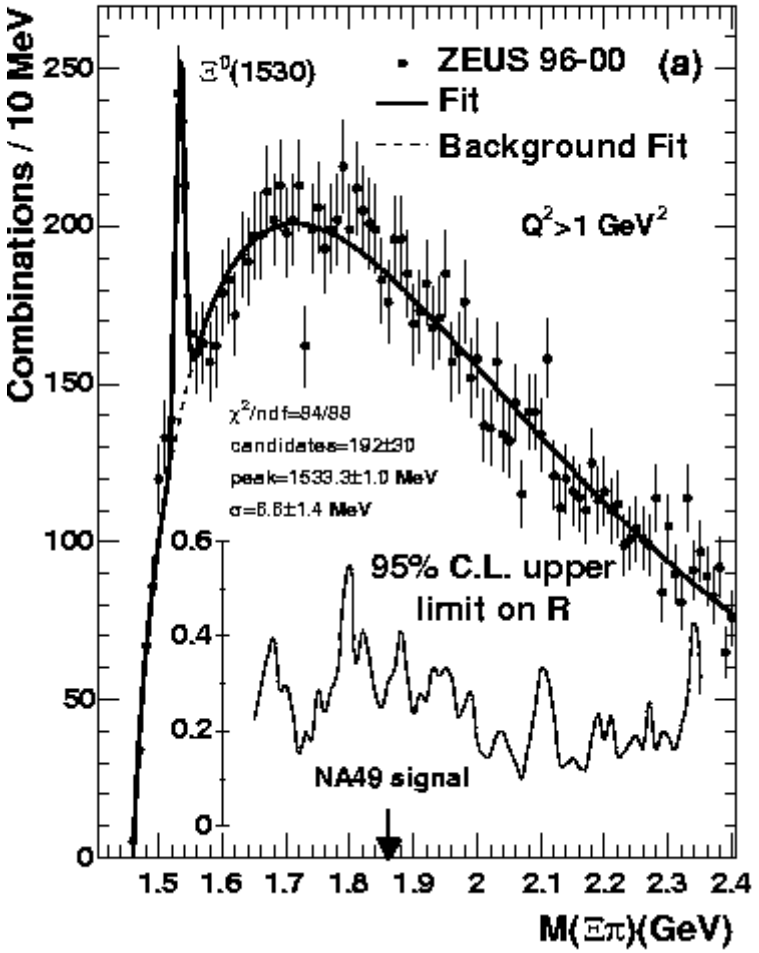
Λ candidates ~ 150000





Ξ^- candidates ~ 3000

ZEUS search for PQ decaying to $\Xi^-\pi^\pm$



No pentaquark signal observed!

Known $\Xi^0(1530)$ state well visible

Negative result also in similar analysis for $Q^2>20GeV^2$ (kinematic region where Θ^+ best seen in ZEUS)

DESY 05-018

H1 search for $\Theta^0_c \to D^{*-(+)} p^{(-)}$

If strange-flavored pentaquarks exist,
they should also exist with charm flavor

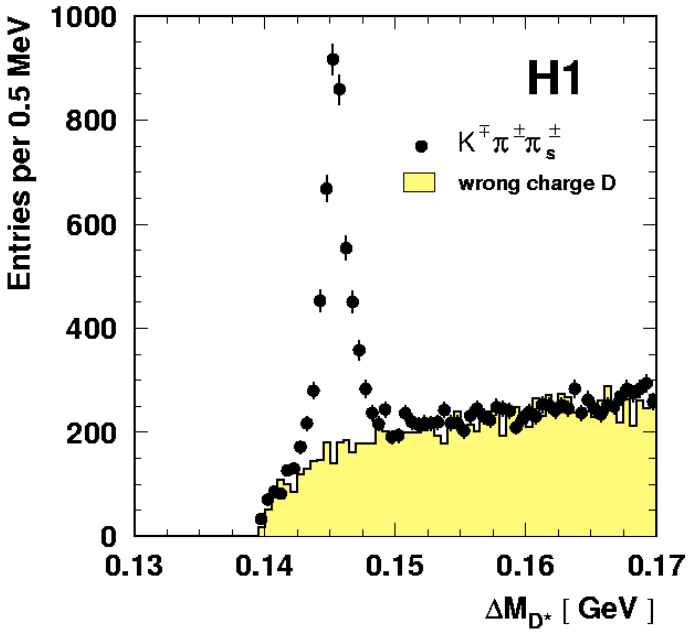
$1 < Q^2 < 100\ \mathrm{GeV}^2$

$0.2 < y < 0.7$

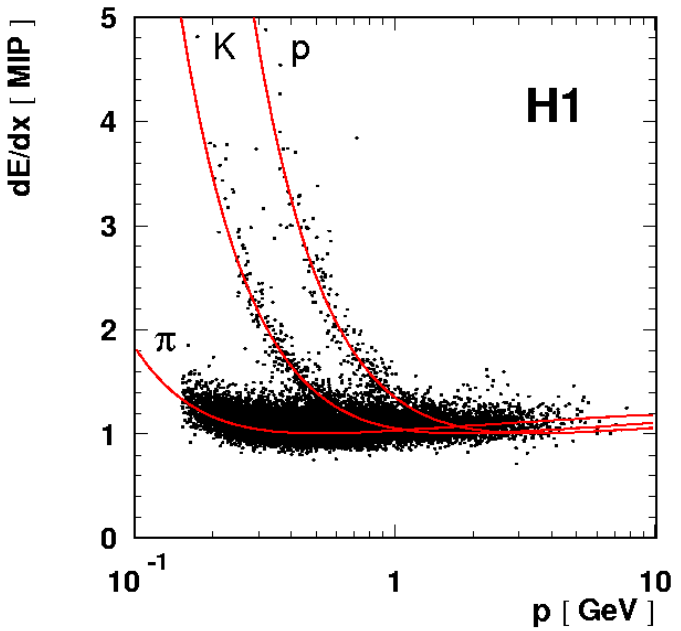
$p_T(D^*) > 1.5\ \mathrm{GeV}$

$|\eta(D^*)| < 1.5$

inelasticity $z(D^*) > 0.2$



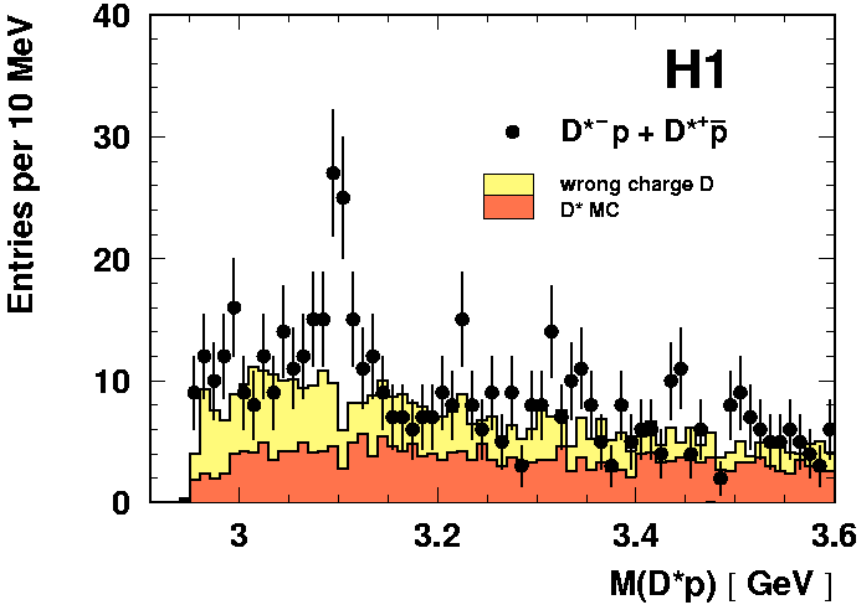
D* selected in a ±2.5MeV window
around the peak: 3400 candidates



Proton identification via dE/dx
resolution ~8%

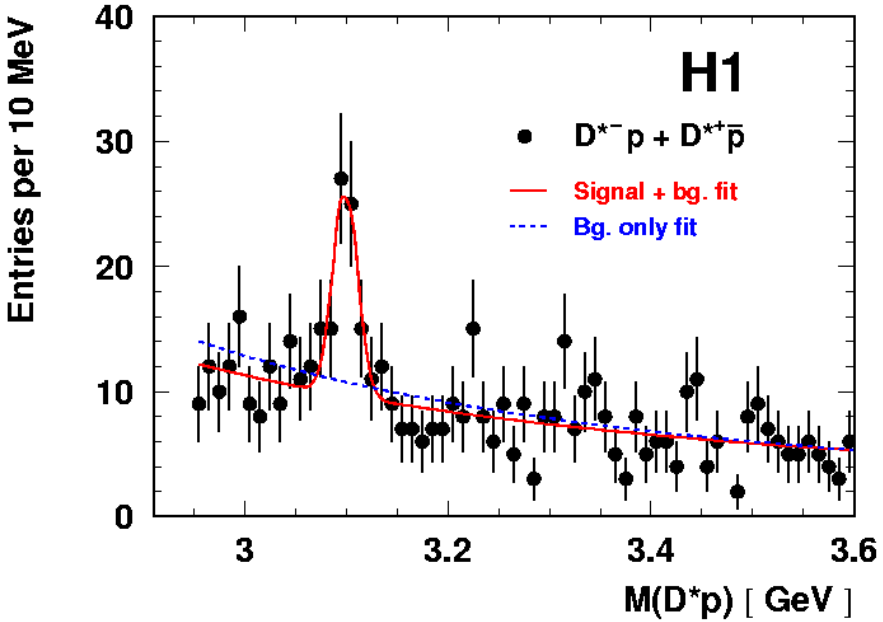
H1 search for $\Theta^0_c \to D^{*-(+)}\overset{(-)}{p}$

D*p mass distribution:
$M(D^*p) = m(K\pi\pi p) - m(K\pi\pi) + M_{PDG}(D^*)$



Signal visible in $D^{\bar{*}+}p$ and $D^{*-}p$ separately with same significance and in different data taking periods

Gaussian fit with free parameters for peak position, width and normalization



Mass: 3099 ±3(stat.) ±5(syst.) MeV
Width: 12±3 MeV
Signal: N_s=50.6±11.2 events

Bgnd only fit: N_b=51.7±2.7 events

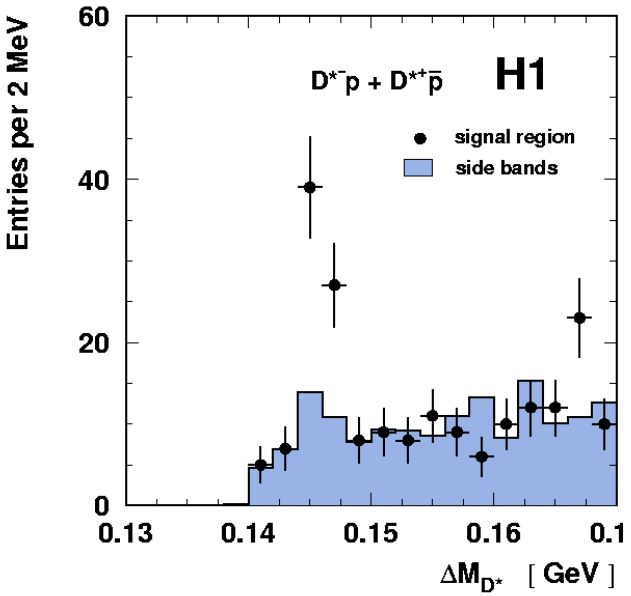
Bgnd fluctuation probability: 5.4σ

Observed D*p resonance estimated to contribute ~1% of the total D* production rate in the kinematic region studied

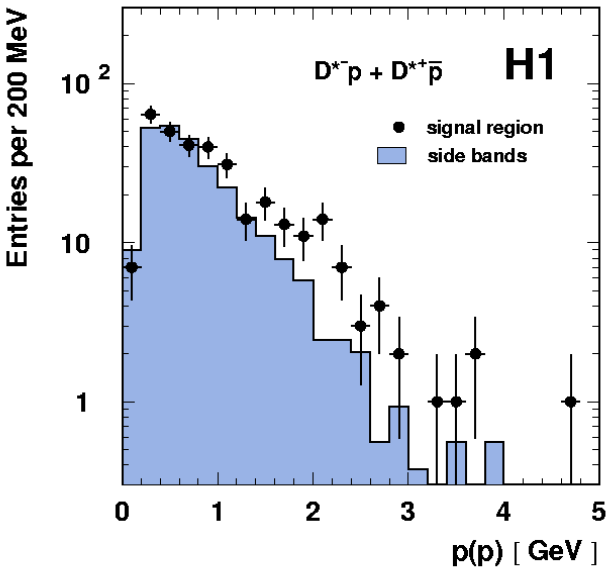
H1 search for $\Theta^0_c \to D^{*-(+)} p^{(-)}$

Kinematics of *D** and *proton* candidates from decay of a resonance expected to be different from those of the background distribution

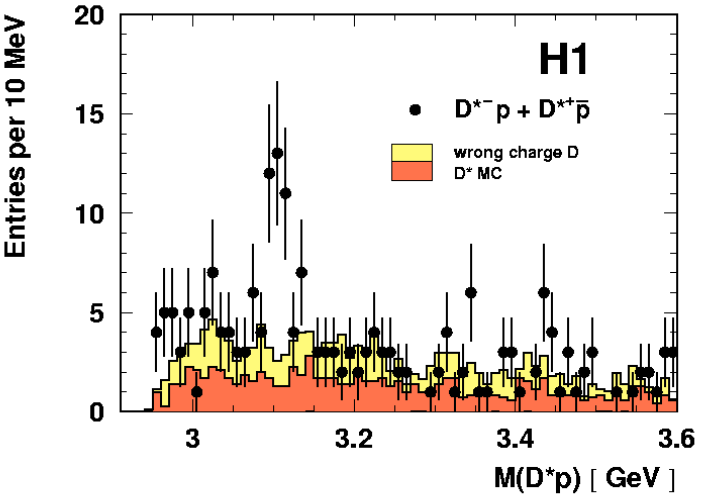
$D^* p$ signal region richer in D^* than side regions



No dE/dx cut, proton candidates from signal region have harder momentum



No dE/dx cut, signal-to-background ratio improves as p(*p*) increases (> 2GeV)



Signal visible also in photoproduction (not shown), but with higher background contamination

Phys. Lett. B588 (2004) 17-28

ZEUS search for $\Theta^0_c \to D^{*-(+)}\overline{(p)}$

$L = 126\ pb^{-1}$

*D** reconstructed in two channels:

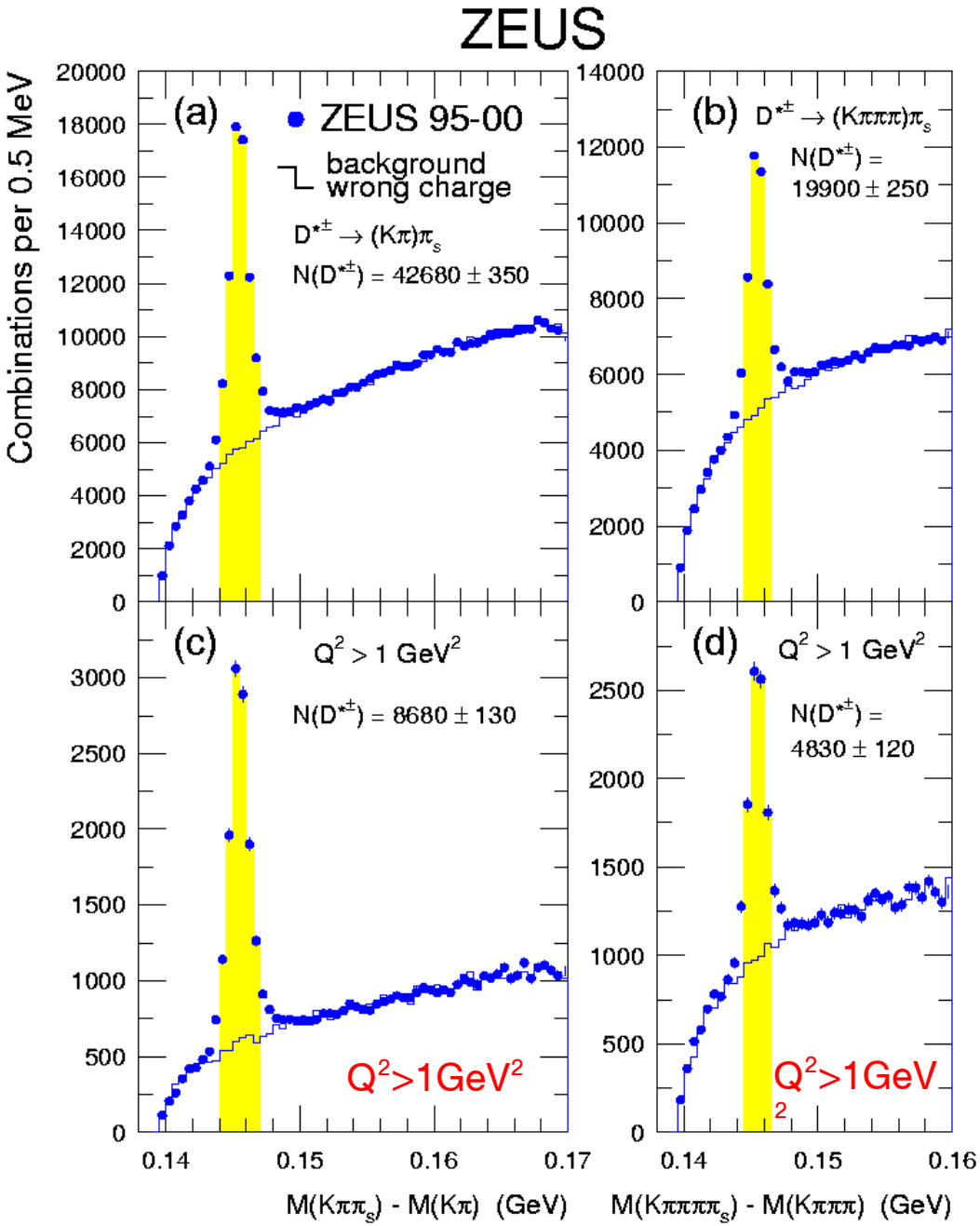
1) $D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$
2) $D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+\pi^+\pi^-)\pi_s^+$

(+ c.c.)

D* candidates: 62000 (total)

13000 ($Q^2>1GeV^2$)

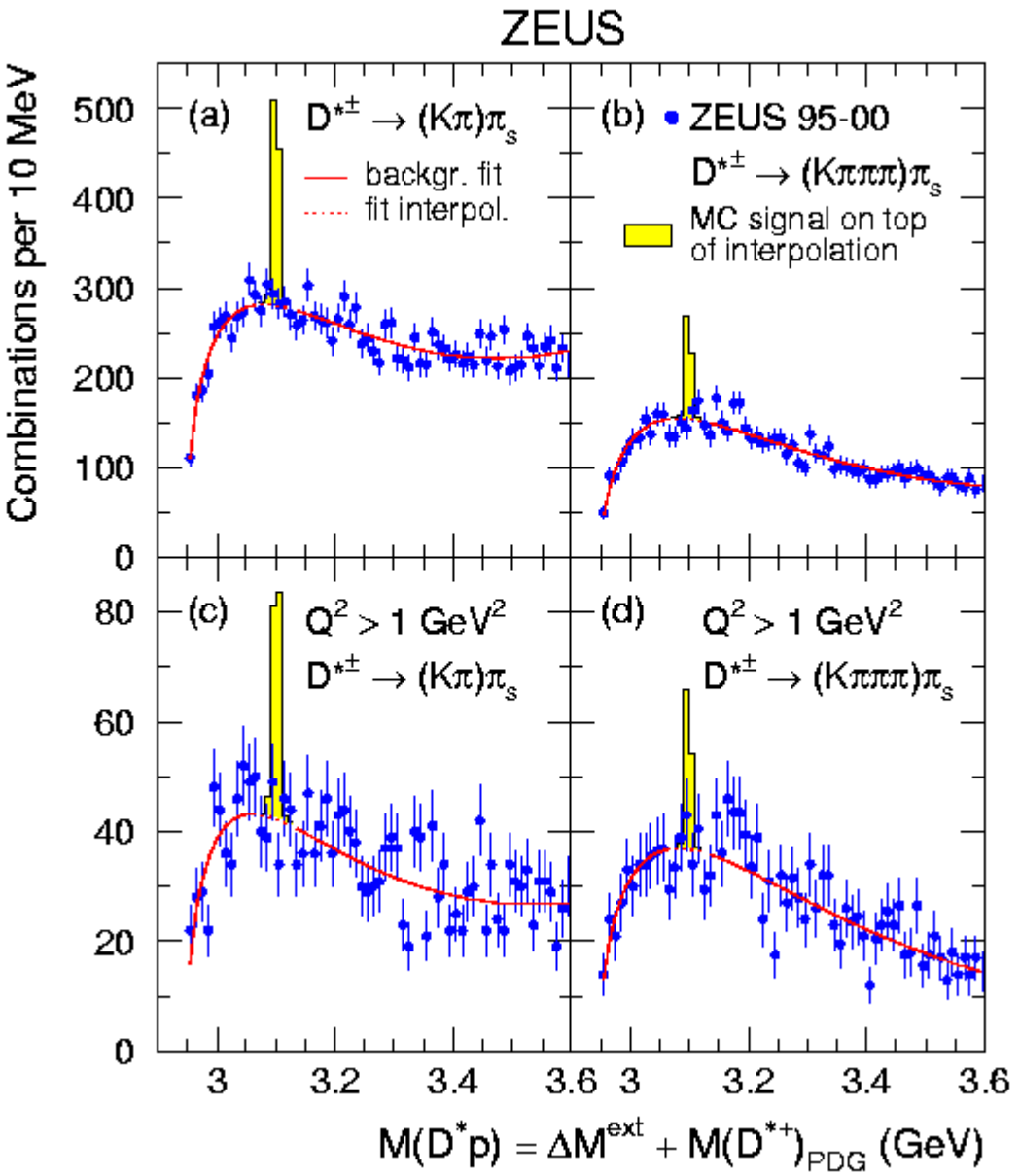
proton identification via dE/dx
resolution 9% (similar to H1)



ZEUS search for $\Theta^0_c \to D^{*-(+)} p^{(-)}$

MC signal normalized to 1% of observed *D**

No sign of the H1 pentaquark signal



Upper limit on fraction of *D** originating from Θ^0_c decay for Q^2>1GeV^2: 0.35% at 95% C.L.

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Summary and outlook

Heavy Flavors:

- charm DIS cross sections in good agreement with NLO QCD even in region at very low Q^2
- charm fragmentation in agreement with e^+e^- results
- beauty cross sections in reasonable agreement with NLO QCD, but data tend to be above theory
- first measurement of F_2^{bb} at $Q^2>150GeV^2$ reported by H1

Pentaquarks:

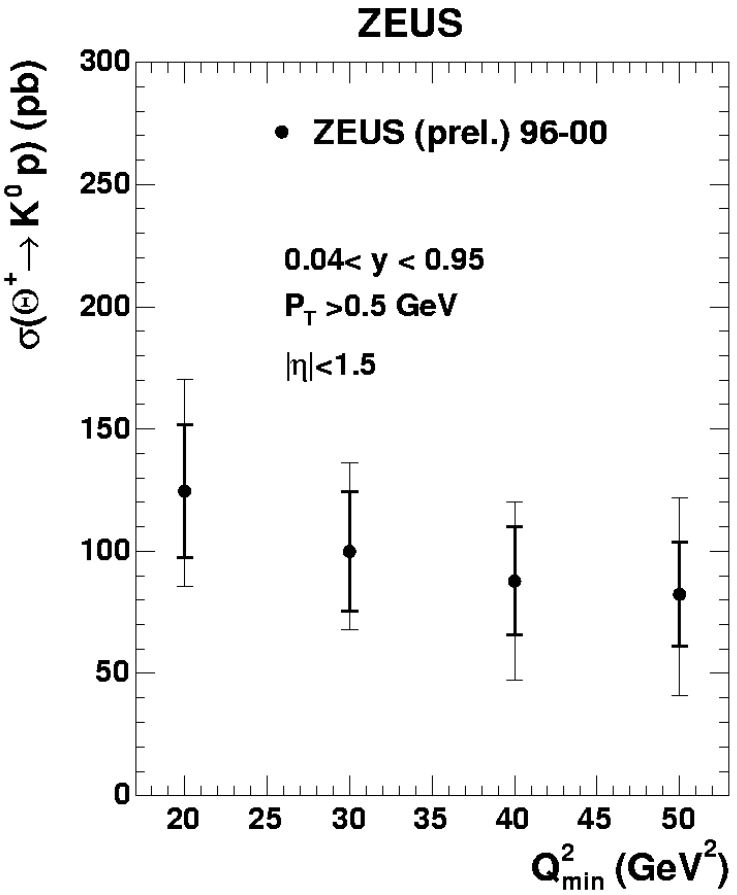
- $\Theta^+(1530)$: signal of a few sigmas in ZEUS
- $\Xi^{--}(1860)$: not confirmed by ZEUS
- $\Theta_c^0(3100)$: signal in H1, not confirmed by ZEUS

HERA II:

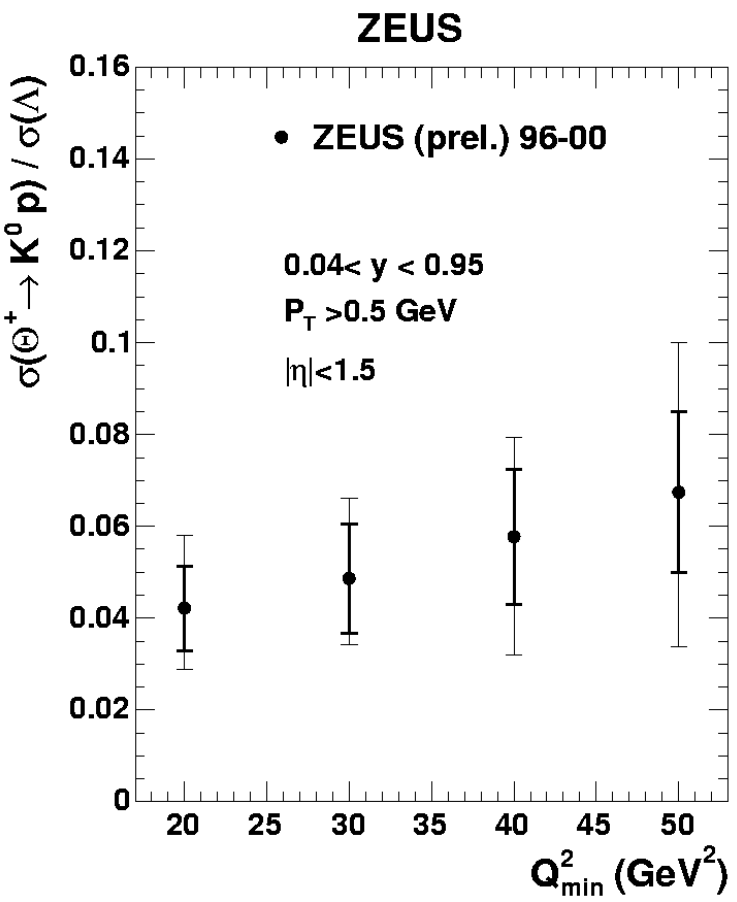
- data taking started in 2003, ~40pb^{-1} delivered with e^+p switched to e^-p at end of 2004, ~20pb^{-1} already integrated data taking will end in 2007
- improved analyses and detector performances (e.g. ZEUS MVD)

Backup: ZEUS search for $\Theta^{+(-)} \rightarrow \overline{(p)} K^0_s$

preliminary



measured cross sections



$\sigma(\Theta) / \sigma(\Lambda)$