Charm pentaquark search

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for the ZEUS Collaboration

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O U T L I N E :

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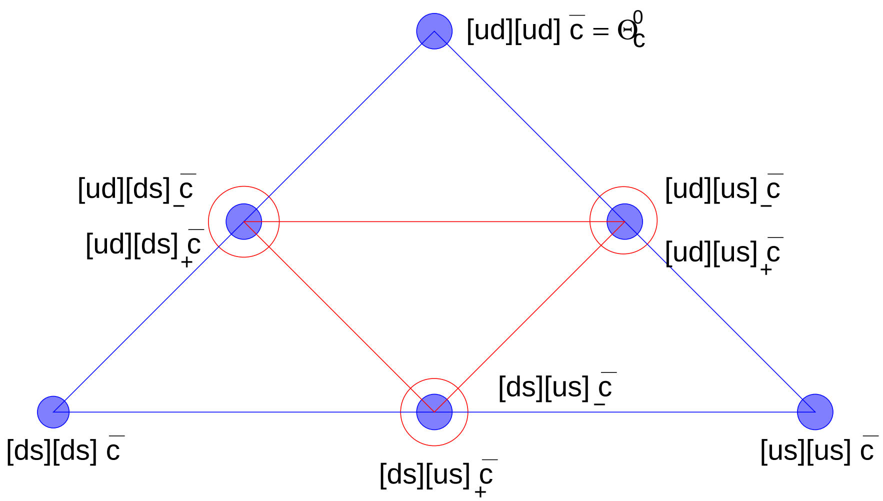


$\Theta^+ = (ud)^2\bar{s}$ seen by many experiments (and by ZEUS)

What about $\Theta^0_c = (ud)^2\bar{c}$?

Introduction

Predictions:

Jaffe-Wilczek (hep-ph/0307341): $M(\Theta_c^0) = 2710\,\mathbf{MeV}$

Wu-Ma (hep-ph/0402244): $\bar{m}(\Theta_c^0) = (4M(\Theta_c^{0*}) + 2M(\Theta_c^0))/6 = 2704\,\mathbf{MeV}$

Such Θ_c^0 would be too light to decay to D mesons

can decay weakly to $\Theta^+\pi^-$

Karliner-Lipkin (hep-ph/0307343): $M(\Theta_c^0) = 2985 \pm 50\,\mathbf{MeV}$

$\Gamma(\Theta_c^0) \sim 21\,\mathbf{MeV}$

Cheung (hep-ph/0308176): $M(\Theta_c^0) = 2938 - 2997\,\mathbf{MeV}$

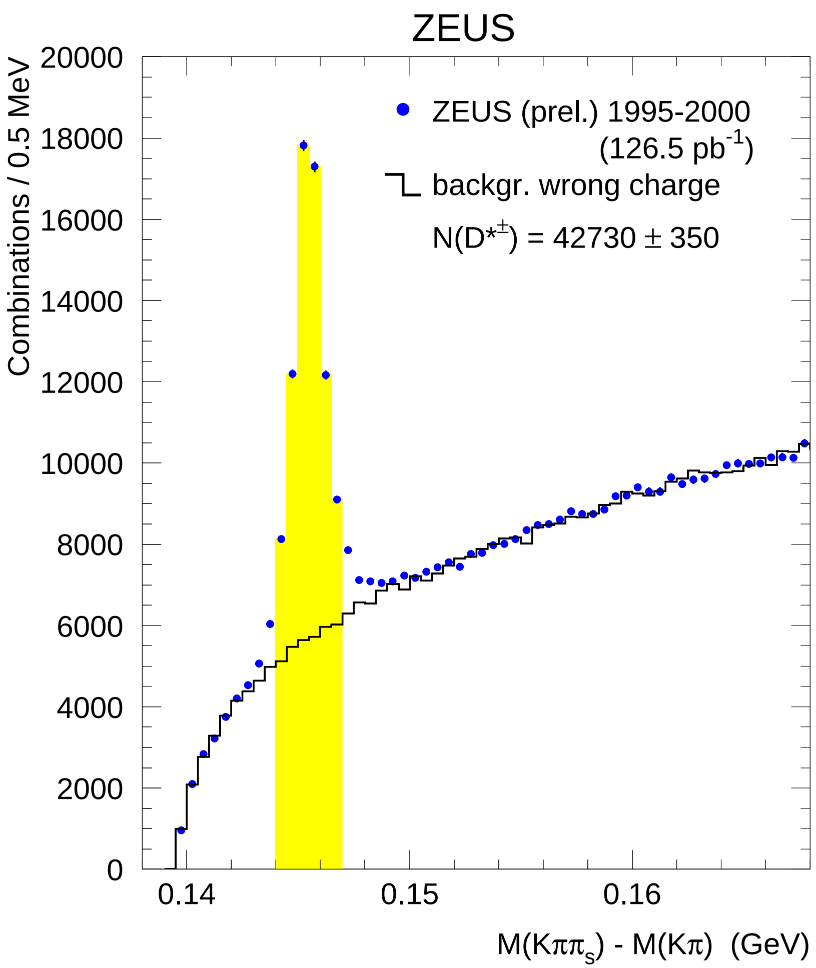
Such Θ_c^0 would decay to D^-p (+ c.c.)

If $M(\Theta_c^0) > M(D^{*+}) + M(p) = 2948\,\mathbf{MeV}$, Θ_c^0 can decay to $D^{*-}p$ (+ c.c.)

This decay mode can be dominant (Karliner-Lipkin, hep-ph/0401072)

We report a search for Θ_c^0 signal in $M(D^{*-}p)$ (+ c.c.) spectra

Procedure: $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+$ reconstruction



$$\Delta M = M(K\pi\pi_s) - M(K\pi)$$

DATA 1995-2000 (126.5 pb^{-1})

$P_T(D^{*\pm}) > 1.35$ **GeV,** $|\eta(D^{*\pm})| < 1.6$

Candidates with $144 < \Delta M < 147$ **MeV (yellow band) were used. In this range after background subtraction:**

$$N(D^{*\pm}) = 42730 \pm 350$$

Summary of cuts:

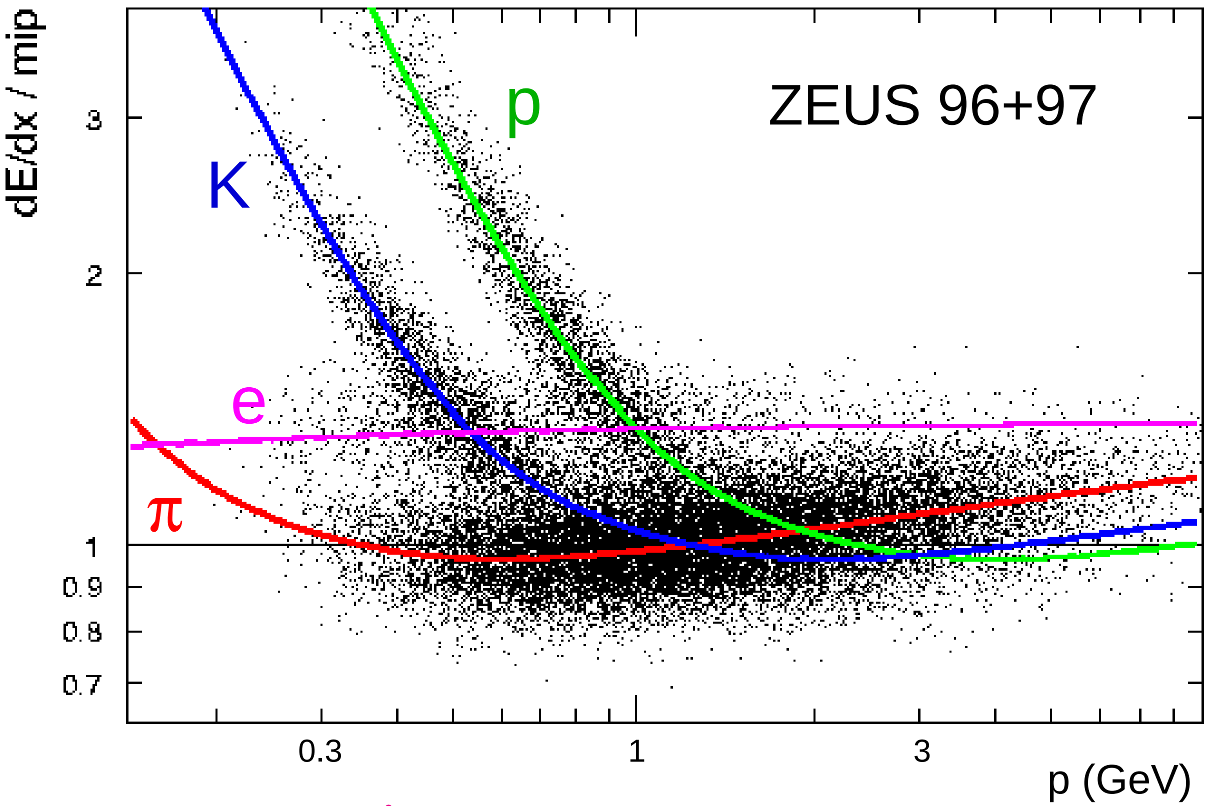
$P_T(K) > 0.45$ **GeV,** $P_T(\pi) > 0.45$ **GeV**

$P_T(\pi_s) > 0.10$ **GeV**

$P_T(D^{*\pm})/E_T^{\text{out } 10^\circ} > 0.12$

$1.83 < M(K\pi) < 1.90$ **GeV (wider for high** $P_T(D^{*\pm})$**)**

Procedure: selection of p candidates



$P_T(p) > 0.15\,\mathbf{GeV}$

dE/dx can be tried it is effective mostly for low-P protons

protons from $5q$ decays can/should be faster than a bulk of π, K

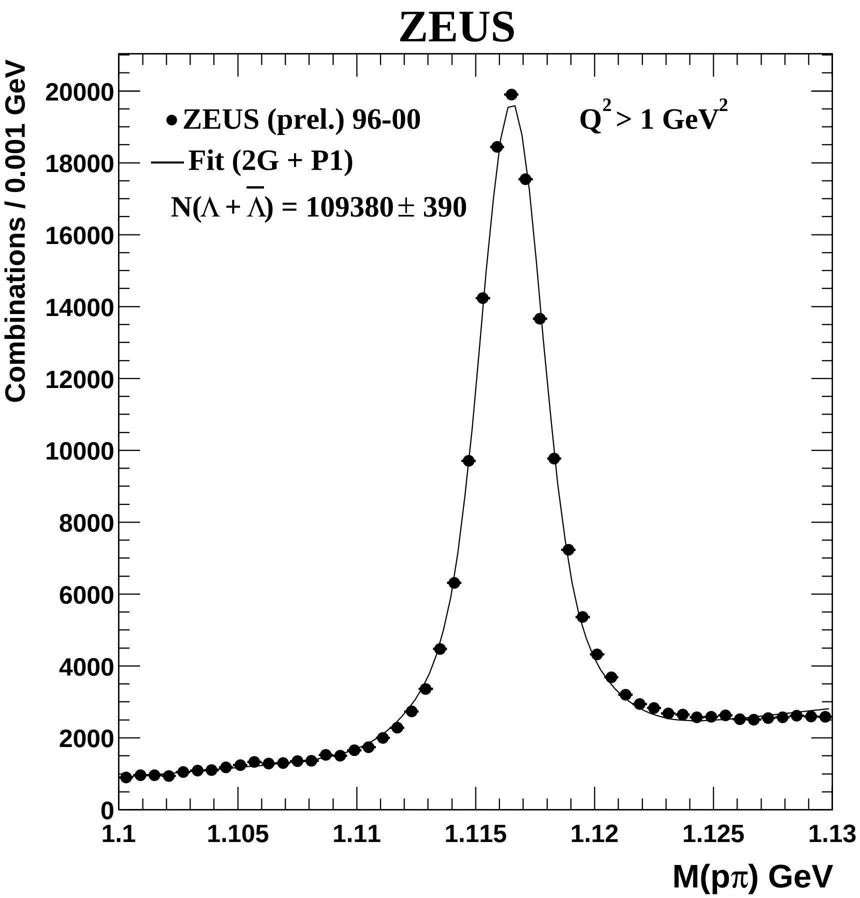
two strategies:

1) select protons with $P < 1.35\,\mathbf{GeV}$ and require $dE/dx > 1.3$

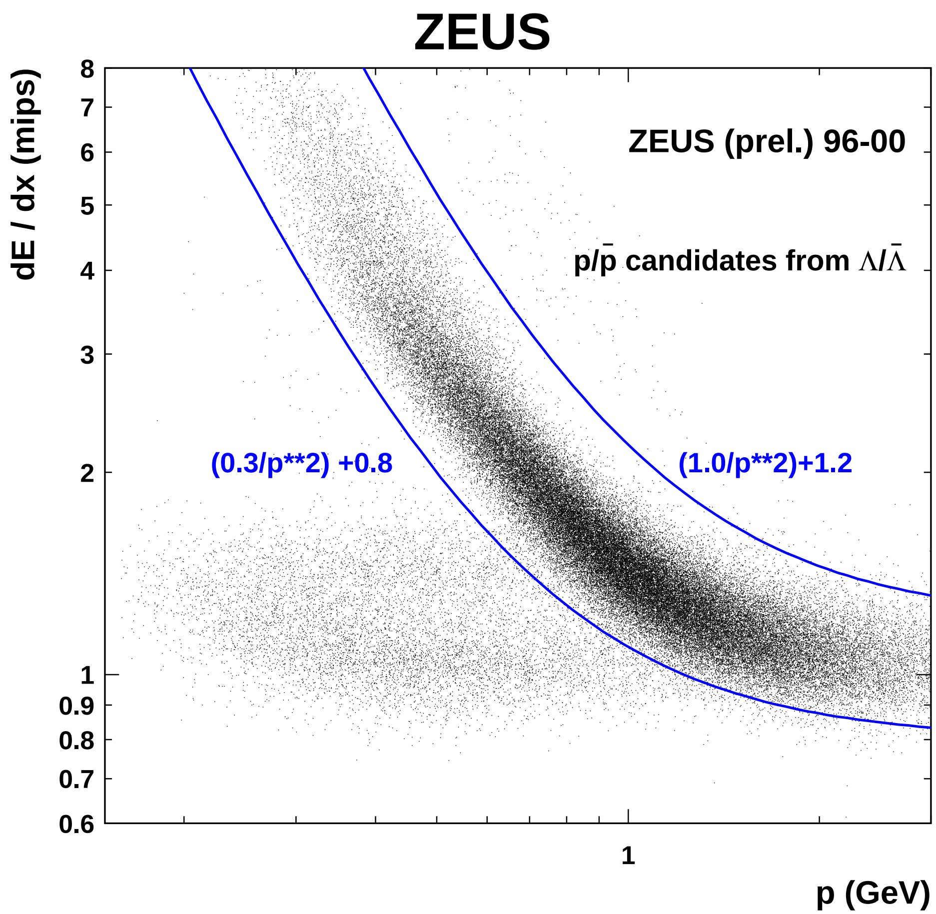
2) select protons with $P > 2\,\mathbf{GeV}$

In addition, require lower/upper limit from the proton dE/dx band tuned in the ZEUS non-charm pentaquark analysis

Procedure: proton dE/dx band



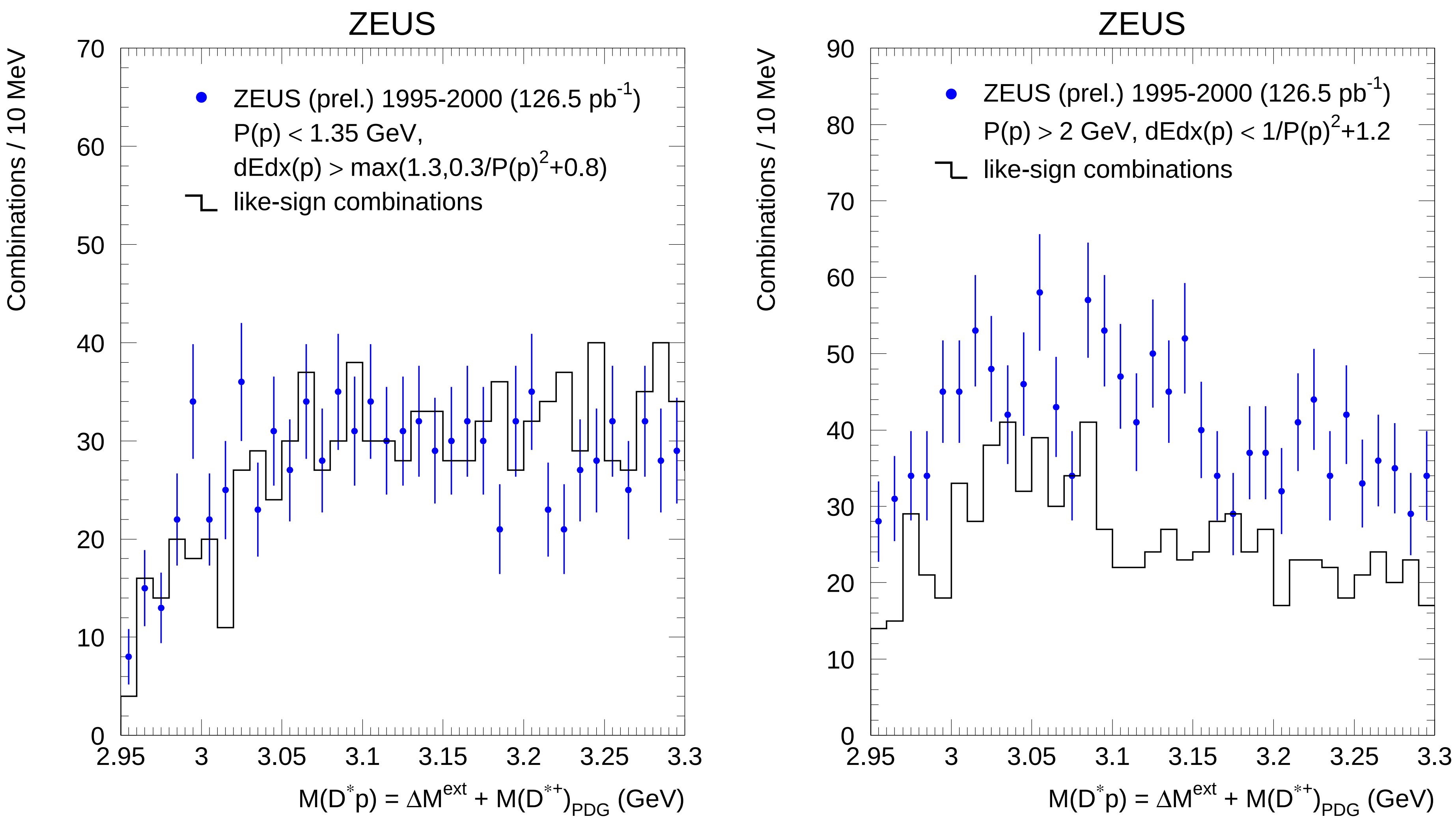
$\Lambda^0 \to p\pi$ **from sec.vert.**



dE/dx **for** $p/\bar{p}$ **candidates**

$$0.3/P^2 + 0.8 < dEdx < 1.0/P^2 + 1.2$$

Measured $M(D^*p)$ spectra



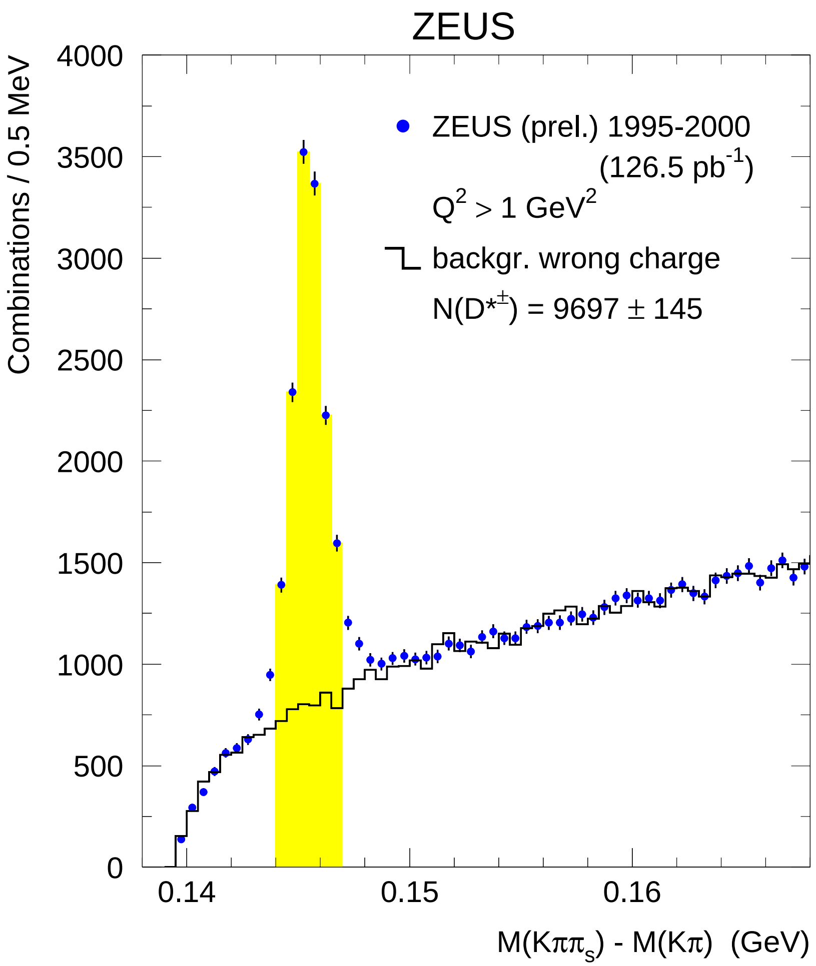
$$M(D^*p) = \Delta M^{\rm ext} + M(D^{*+})_{\rm PDG} = M(K\pi\pi_s p) - M(K\pi\pi_s) + M(D^{*+})_{\rm PDG}$$

pitifully, no signal observed ...

Procedure: $D^{*\pm}$ in DIS with $Q^2 > 1\,\mathbf{GeV}^2$

Charm fragmentation universality requires $f(c \to \Theta_c^0)$ to be the same in ep, γp, pp and other interactions

Still it is useful to check DIS alone because it permits cleaner selection (smaller $W_{\gamma p} \Longrightarrow$ smaller multiplicities)



DATA 1995-2000 (126.5 pb^{-1})

$P_T(D^{*\pm}) > 1.35\,$**GeV**, $\quad |\eta(D^{*\pm})| < 1.6$

$E_{e'} > 8\,$**GeV**, $\quad Q^2 > 1\,$**GeV**^{2}

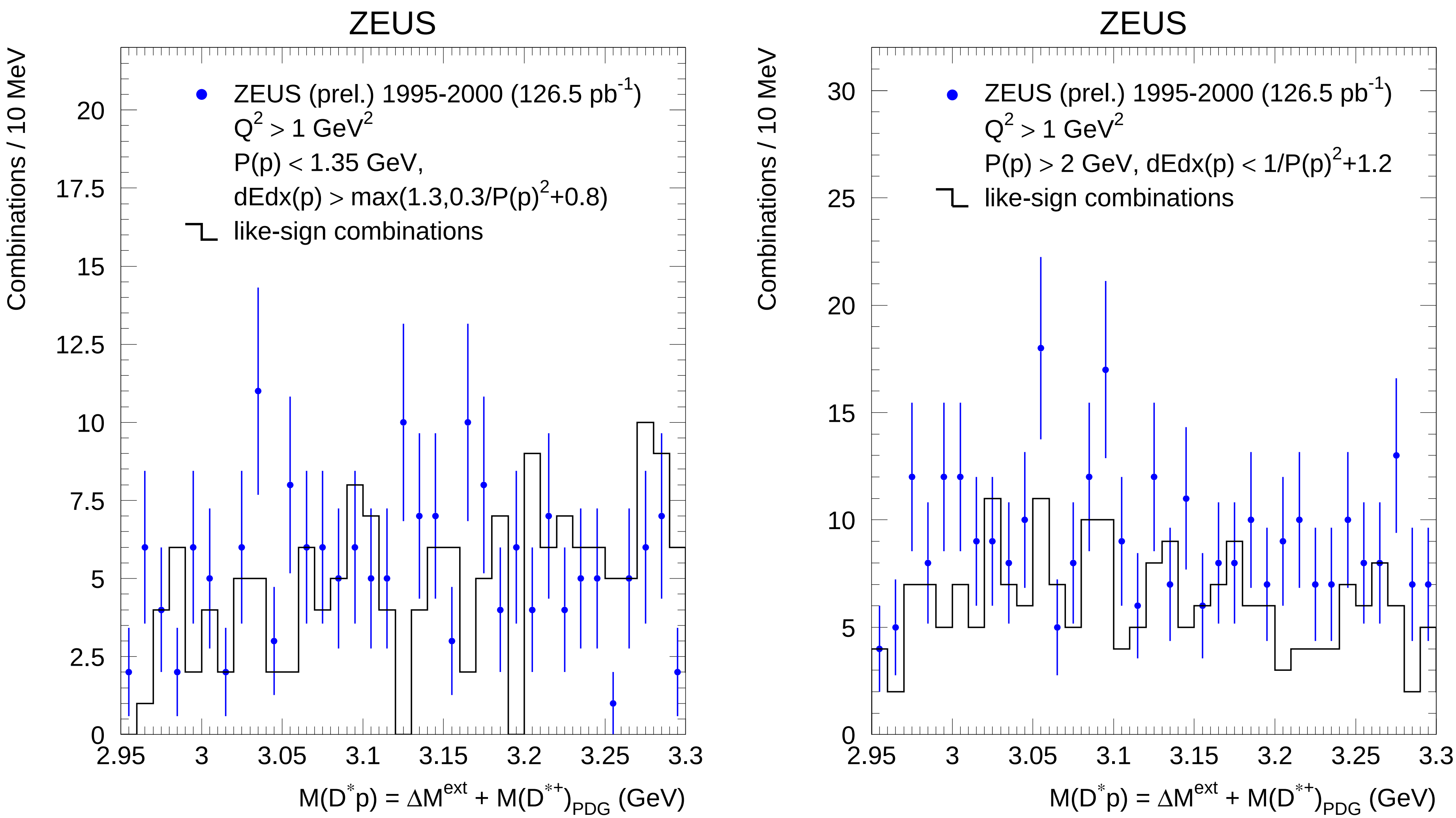
$$N(D^{*\pm}) = 9697 \pm 145$$

signal is cleaner

but ~ 4.5 times smaller

than in inclusive case

Measured $M(D^*p)$ spectra in DIS with $Q^2 > 1\,\mathrm{GeV}^2$



$$M(D^*p) = \Delta M^{\rm ext} + M(D^{*+})_{\rm PDG} = M(K\pi\pi_s p) - M(K\pi\pi_s) + M(D^{*+})_{\rm PDG}$$

again, nothing to fit ...

Systematic studies

selecting of DIS with $Q^2 > 1\,\mathrm{GeV}^2$ (was shown) or $Q^2 > 15\,\mathrm{GeV}^2$

varying dE/dx requirements for low-P selection

no dE/dx requirements for high-P selection

require in addition $\cos\Theta^*(p) > -0.7$, where $\Theta^*(p)$ is the angle between p direction in $5q$ r.f. and $5q$ direction in the lab

studying/removing reflections from $D^{**} \to D^{*\pm}\pi^{\mp}$

removing the cut on $P_T(D^{*\pm})/E_T^{\mathrm{out}\,10^\circ}$; using $z(D^{*\pm}) > 0.2$ instead

making all cuts "as close as possible to H1 selection"

Signal did not show up

Naïve estimation of expected signals

we are not yet ready with the upper limit on

$f(c \rightarrow \Theta_c^0) \times B(\Theta_c^0 \rightarrow D^{*-}p)$

Naïve estimation of expected signals (inspired by H1 observations):

$$\frac{N^{\rm rec}(\Theta_c^0 \rightarrow D^{*-}p + c.c.)}{N^{\rm rec}(D^{*\pm})} \sim 1\%$$

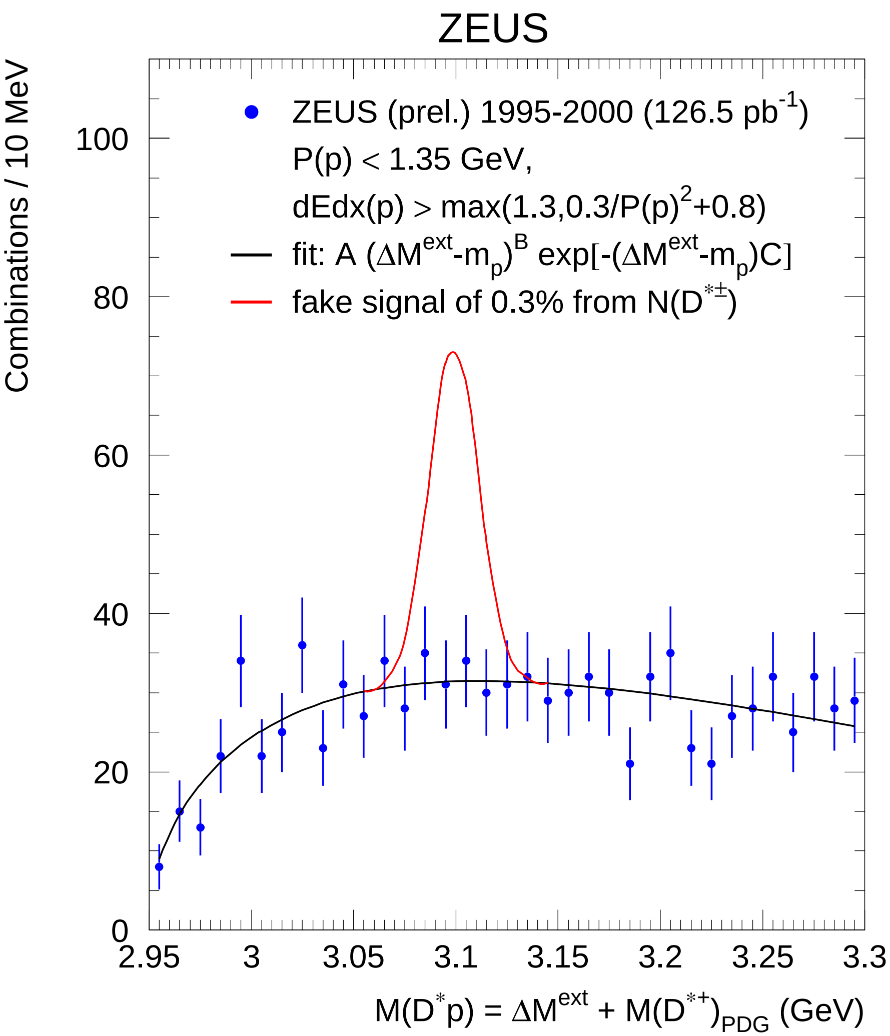
$$\frac{N^{\rm rec}(P(p)<1.35\,{\rm GeV}, dE/dx(p)>1.3)}{N^{\rm rec}({\rm all}\ p)} \sim 30\%$$

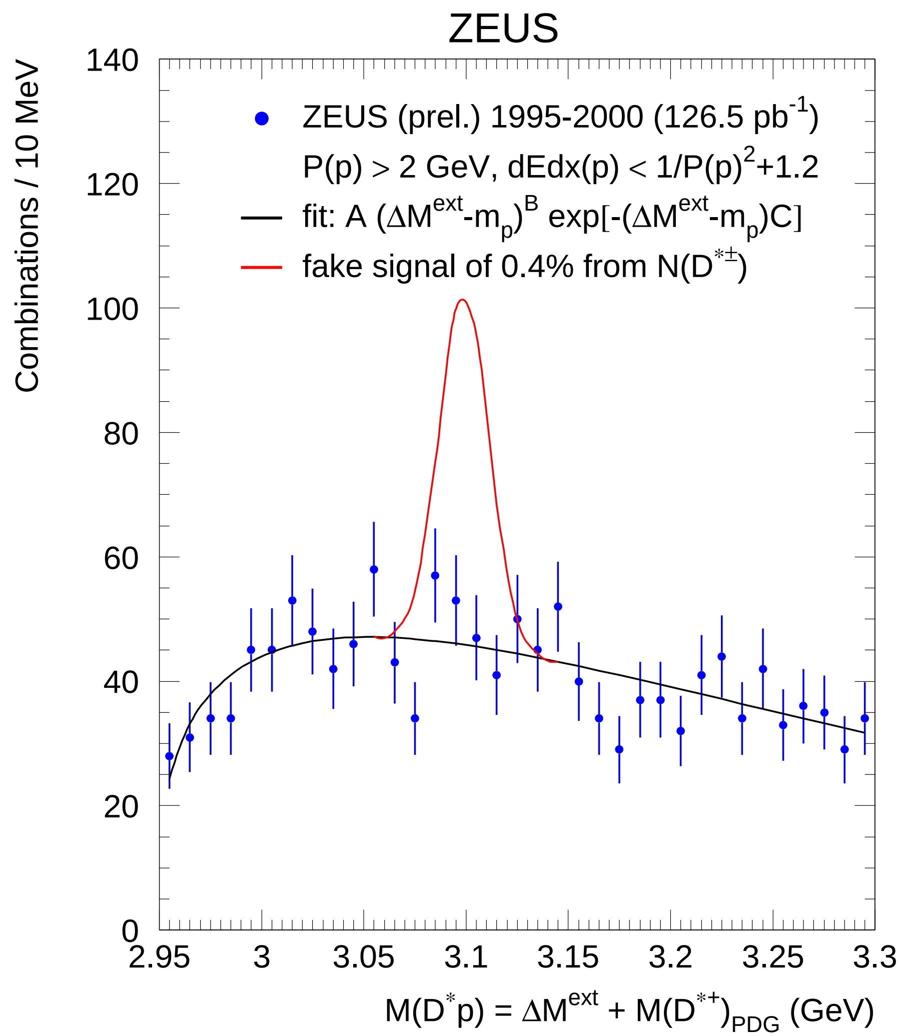
$$\frac{N^{\rm rec}(P(p)>2\,{\rm GeV})}{N^{\rm rec}({\rm all}\ p)} \sim 40\%$$

low-P selection : 0.3% **from** $N(D^{*\pm})$

high-P selection : 0.4% **from** $N(D^{*\pm})$

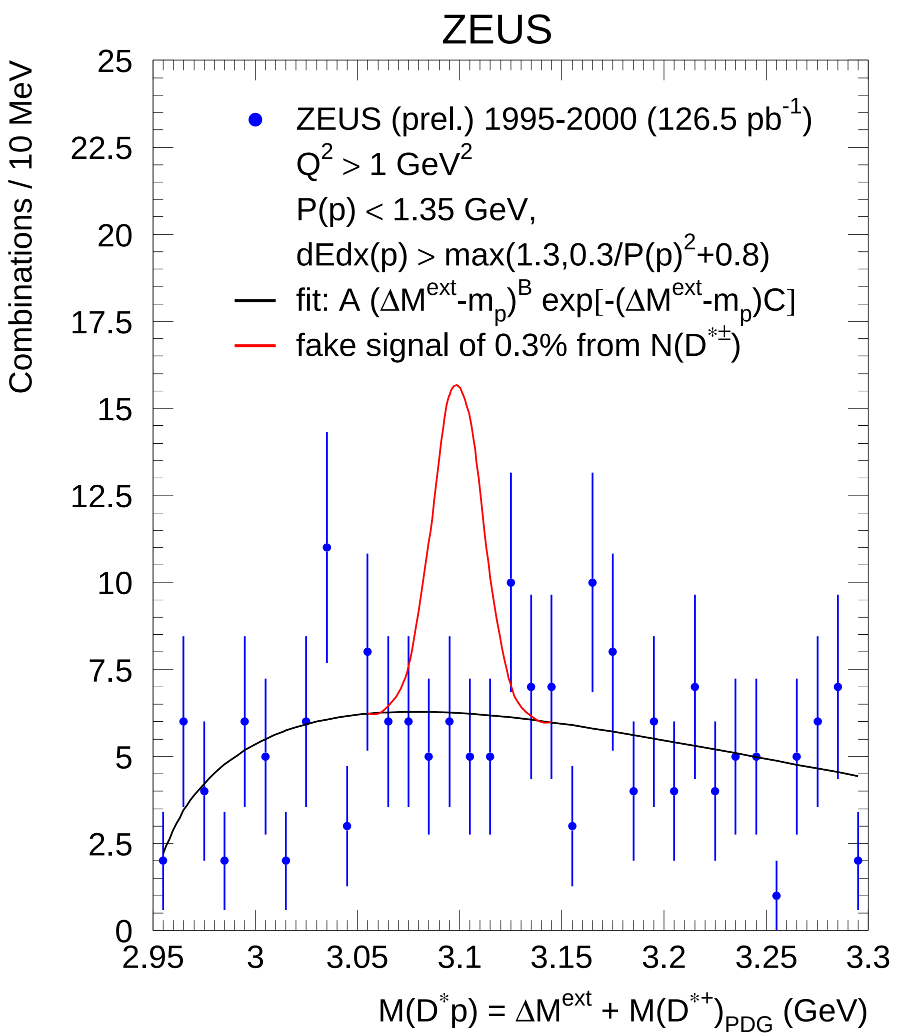
Naïve signal expectations

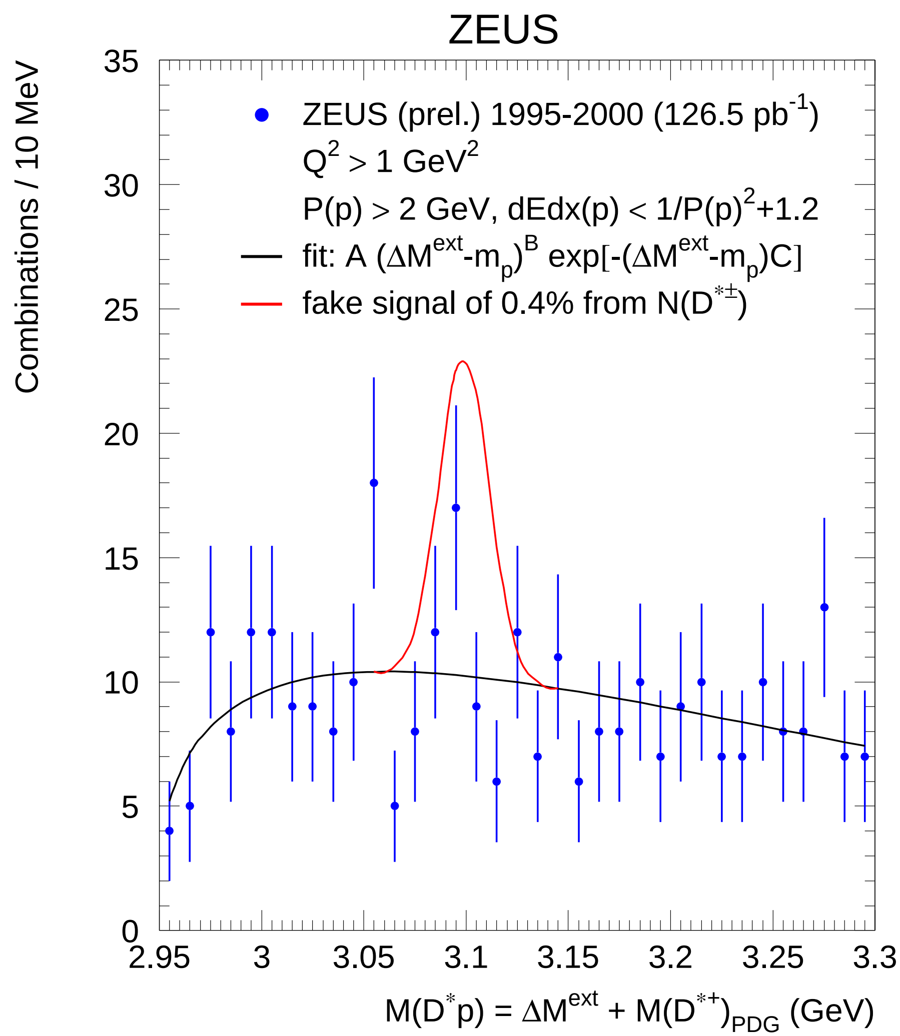




so large signals are excluded

Naïve signal expectations in DIS with $Q^2 > 1\,\mathrm{GeV}^2$





sensitivity is smaller

so large signals are certainly not here

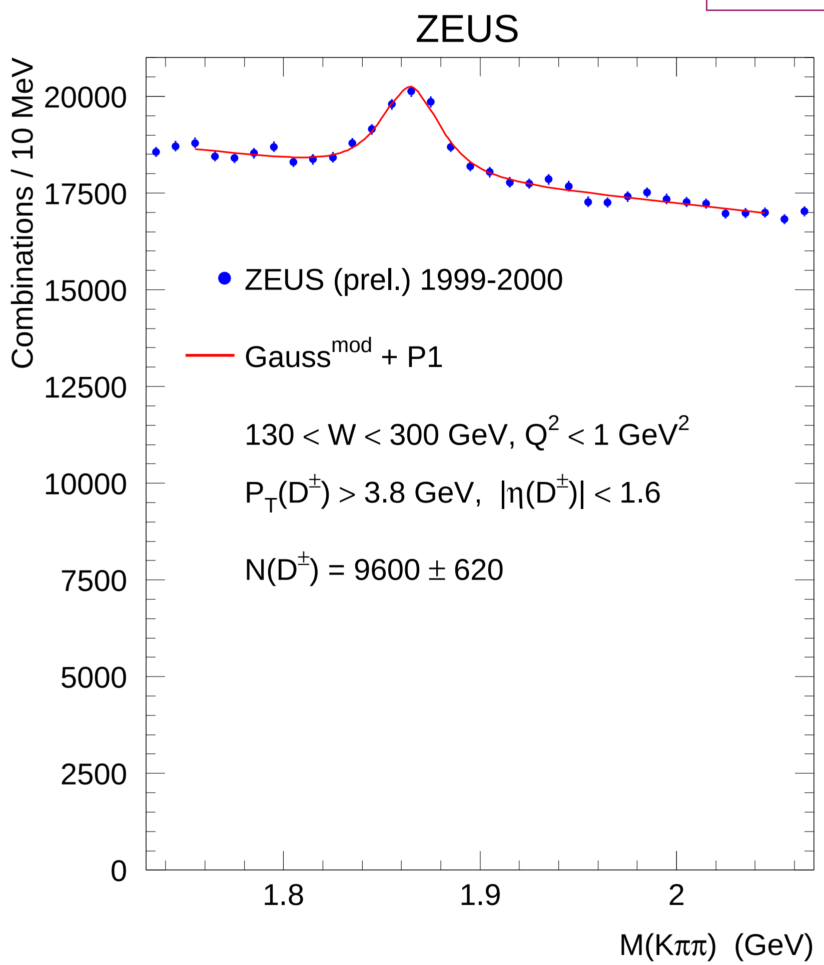
Summary

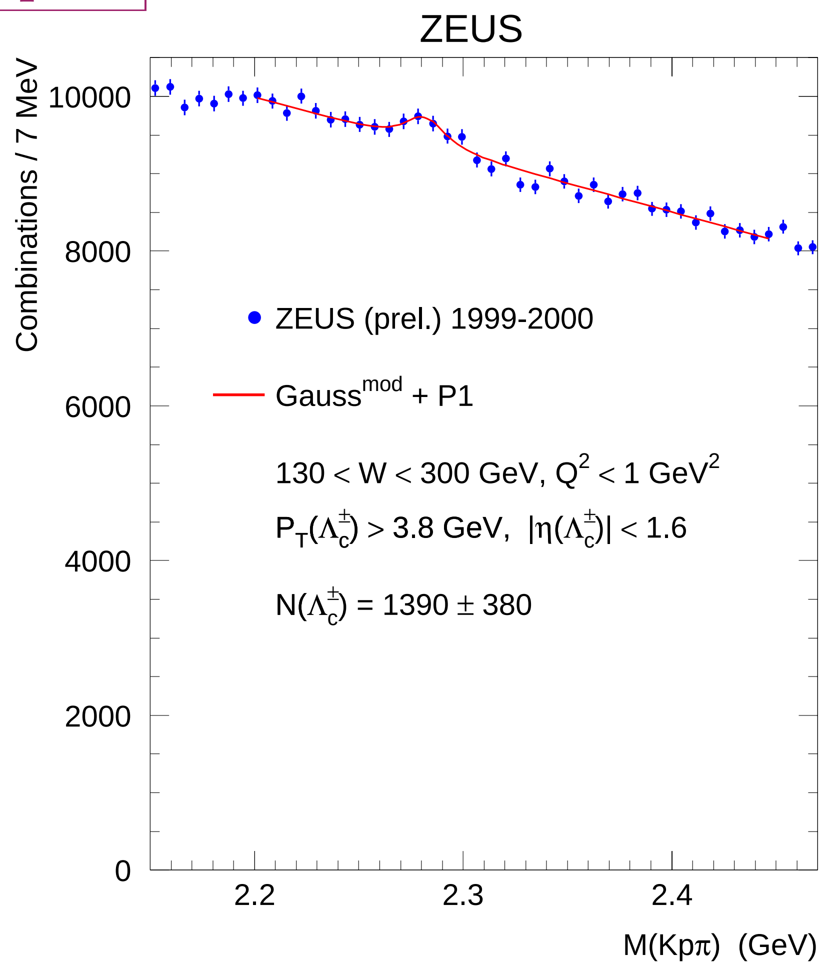
Using all HERA-I data ($126.5\,\mathbf{pb}^{-1}$), the ZEUS collaboration does not see any resonance structure in $M(D^*p)$ spectra

The ZEUS data constrain the uncorrected fraction of $D^{*\pm}$ mesons originating from Θ_c^0 decays to be below 1%

Backup: $D^\pm \to K^\mp\pi^\pm\pi^\pm$ and $\Lambda_c^\pm \to K^\mp p^\pm \pi^\pm$

$\mathcal{L}_{int} = 65.5\,\mathbf{pb}^{-1}$





no lifetime tagging (pre-MVD data)

no dE/dx selection (high-P_T range)

$N(D^\pm) = 9600 \pm 620$

$N(\Lambda_c^\pm) = 1390 \pm 380$

Backup: fragmentation fractions

ZEUS prel. (γp) $P_T(D,\Lambda_c) > 3.8$ **GeV,** $\|\eta(D,\Lambda_c)\| < 1.6$	Combined e^+e^- data	H1 prel. (DIS)
$f(c \to D^+) = 0.249 \pm 0.014^{+0.004}_{-0.008}$	0.232 ± 0.010	$0.202 \pm 0.020^{+0.045}_{-0.033}{}^{+0.029}_{-0.021}$
$f(c \to D^0) = 0.557 \pm 0.019^{+0.005}_{-0.013}$	0.549 ± 0.023	$0.658 \pm 0.054^{+0.117}_{-0.142}{}^{+0.086}_{-0.048}$
$f(c \to D_s^+) = 0.107 \pm 0.009 \pm 0.005$	0.101 ± 0.009	$0.156 \pm 0.043^{+0.036}_{-0.035}{}^{+0.050}_{-0.046}$
$f(c \to \Lambda_c^+) = 0.076 \pm 0.020^{+0.017}_{-0.001}$	0.076 ± 0.007	
$f(c \to D^{*+}) = 0.223 \pm 0.009^{+0.003}_{-0.005}$	0.235 ± 0.007	$0.263 \pm 0.019^{+0.056}_{-0.042}{}^{+0.031}_{-0.022}$

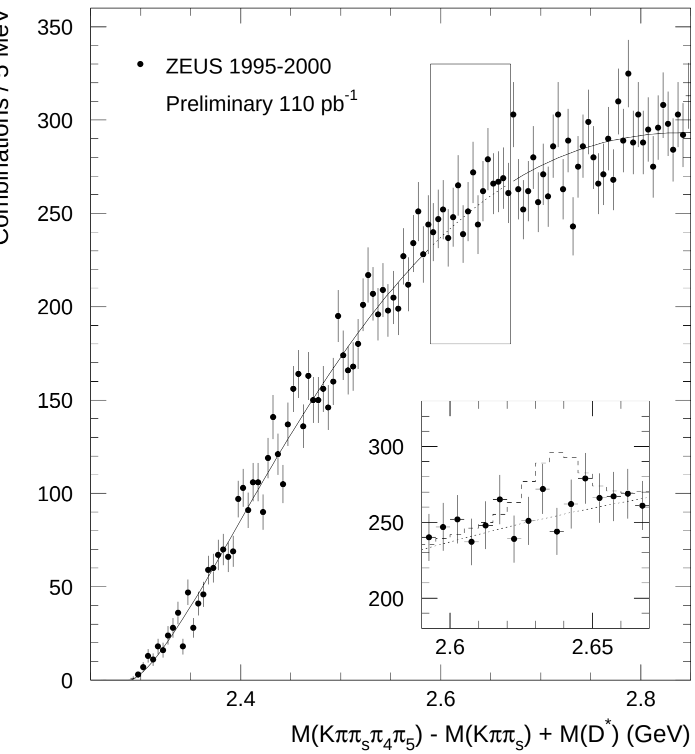
charm fragmentation fractions are universal

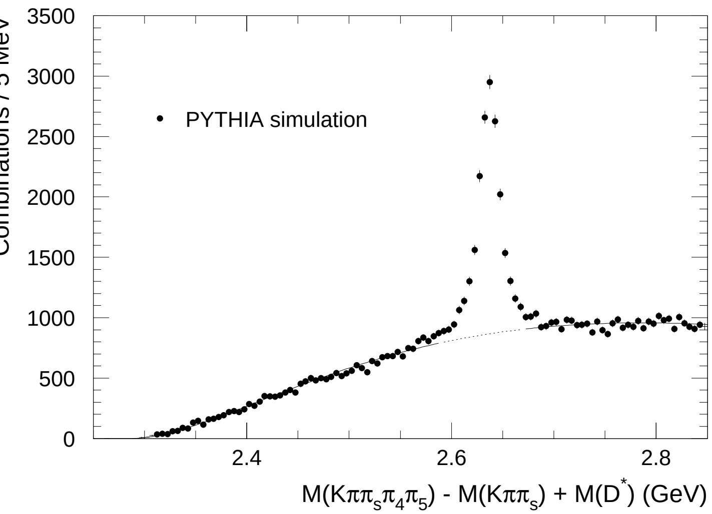
we use correct normalisation for pQCD predictions

HERA measurements confirms universality

of charm fragmentation

Backup: search for radially excited $D^{*\prime\pm}$ meson





$D^{*\prime\pm} \rightarrow D^{*\pm}\pi^+\pi^-$

Observed by DELPHI ($\sim 5\sigma$): $M = 2637\,$**MeV**

$\Gamma < 15\,$**MeV**

CLEO and OPAL did not confirm

$\Longleftarrow$ **ZEUS search**

$\Delta M^{ext} = M(K\pi\pi_S\pi_4\pi_5) - M(K\pi\pi_s)$

Search window: $2.59 < \Delta M^{ext} + M(D^{*+}) < 2.67\,$**GeV**

covers both predictions and DELPHI's observation

after backgr. subtraction: "$N(D^{*\prime\pm})$"$= 91 \pm 75$

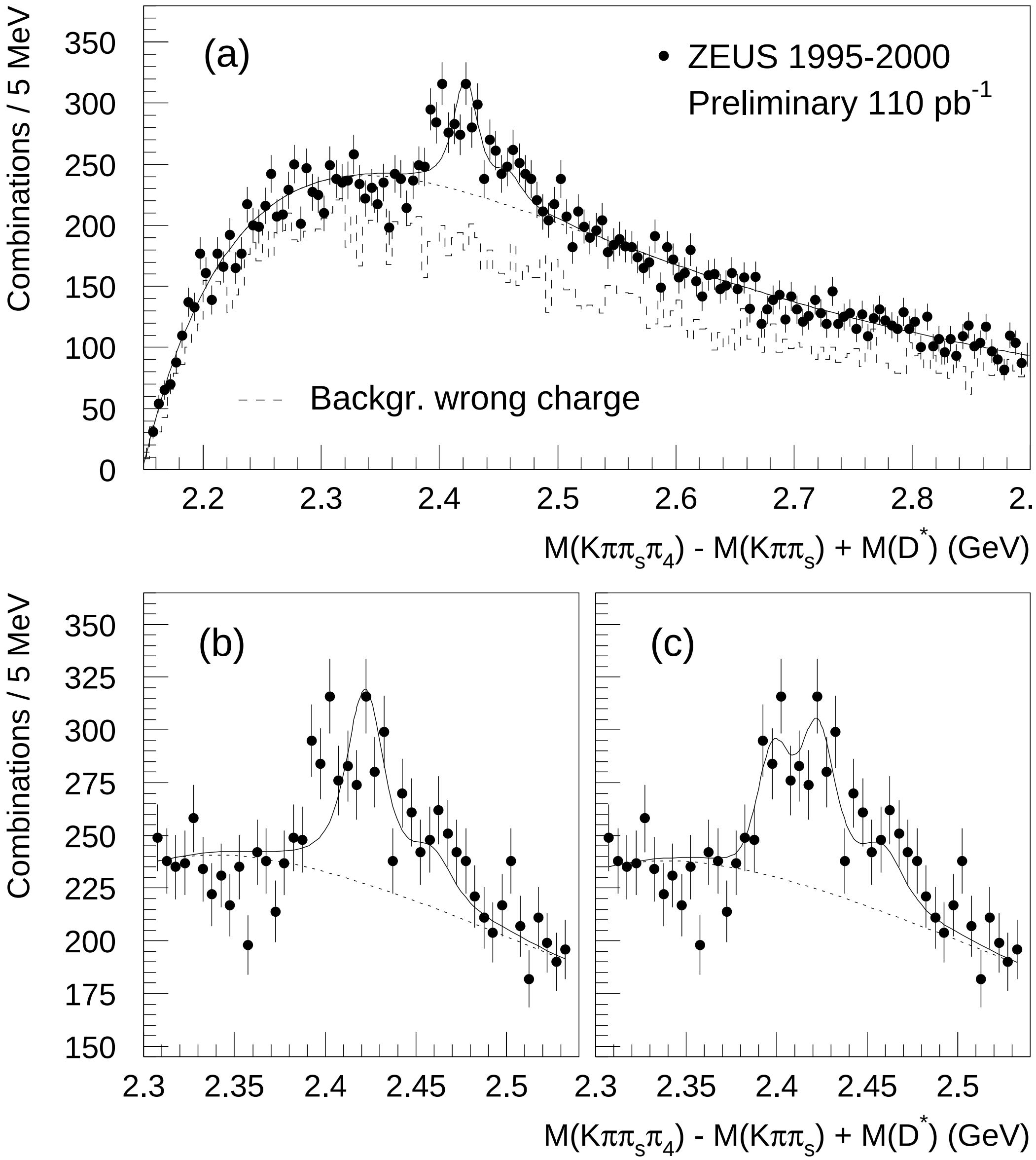
Using world average for $f(c \rightarrow D^{*+})$ **:**

$f(c \rightarrow D^{*\prime+}) \cdot B_{D^{*\prime+} \rightarrow D^{*+}\pi^+\pi^-} < 0.7\%$ (95% C.L.)

(ZEUS prel.)

somewhat stronger than the 0.9% **limit obtained by OPAL**

Backup: orbitally excited P-wave D mesons



$D_1^0, D_2^{*0} \to D^{*\pm}\pi^{\mp}$

$\Delta M^{ext} = M(K\pi\pi_S\pi_4) - M(K\pi\pi_s)$

2-dimensional fit with fixed M, Γ, resolution and helicity distr. :

$\frac{dN}{d\cos\alpha} \propto 1 + 3\cos^2\alpha \qquad (1^+, L+s=3/2)$

$\frac{dN}{d\cos\alpha} \propto 1 - \cos^2\alpha \qquad (2^+, L+s=3/2)$

helicity angle α : between π_4 and π_s in $D^{*\pm}$ rest frame

$N(D_1^0) = 526 \pm 65$

$N(D_2^{*0}) = 203 \pm 60$

Additional narrow bump ?

$N = 211 \pm 49$

$M = 2398.1 \pm 2.1(\text{stat.})^{+1.6}_{-0.8}(\text{syst.})$ **MeV**

New D meson ? Interference ?

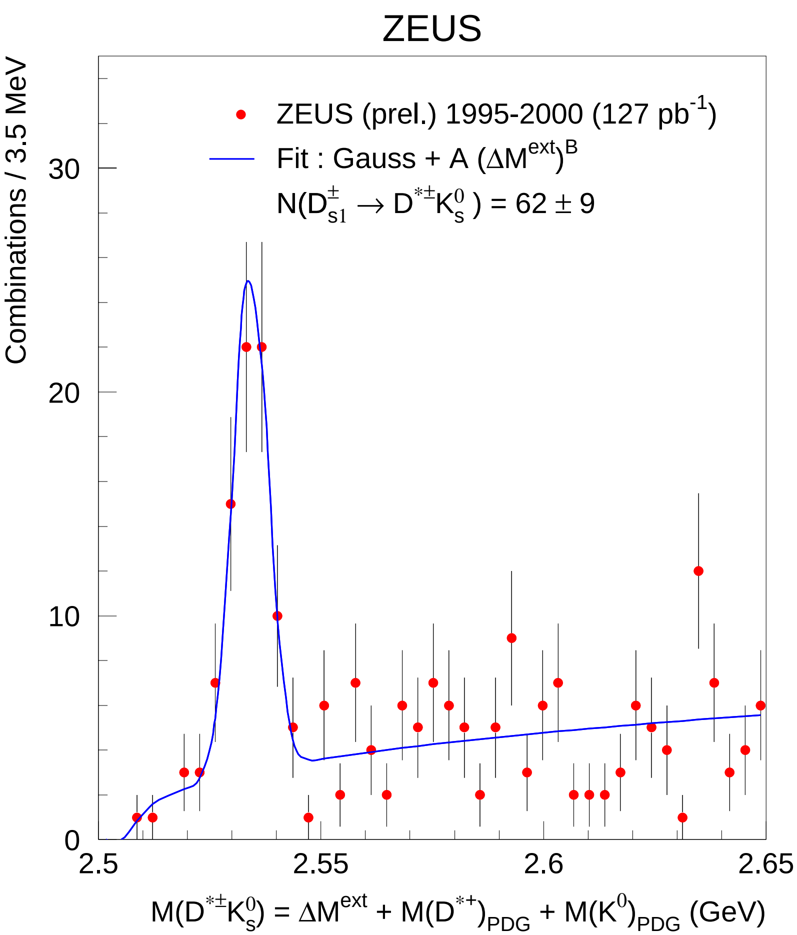
Backup: charm-strange $D_{s1}^{\pm}(2536)$ meson

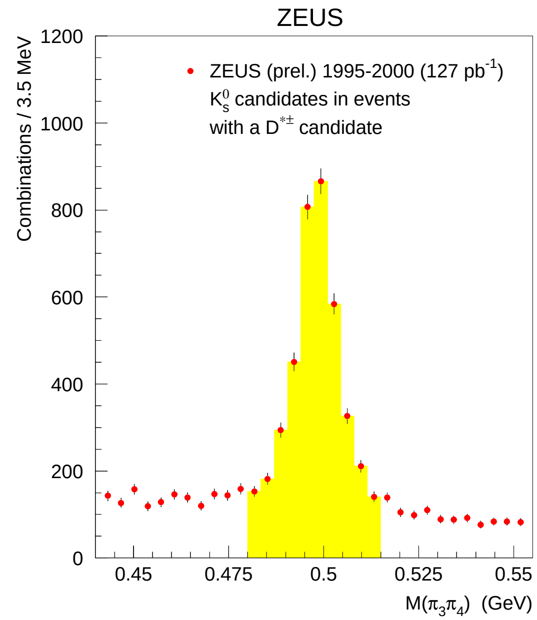
$D_{s1}^{\pm}(2536) \rightarrow D^{*\pm} K_s^0 \;, \qquad K_s^0 \rightarrow \pi^+\pi^-$

$\Delta M^{ext} = M(K\pi\pi_S\pi_3\pi_4) - M(K\pi\pi_s) - M(\pi_3\pi_4)$

$N(D_{s1}^+) = 62.3 \pm 9.3$

$M(D_{s1}^+) = 2534.2 \pm 0.6 \pm 0.5\,\textbf{MeV} \quad (\sim M_{\mathrm{PDG}})$





Helicity angle α : between K_s^0 and π_s in $D^{*\pm}$ r.f.

Fit to a form : $1 + R\cos^2\alpha$

$R = -0.53 \pm 0.32(\mathrm{stat.})^{+0.05}_{-0.14}(\mathrm{syst.})$ **(ZEUS prel.)**

CLEO ($D_{s1}^+ \rightarrow D^{*0}K^+$) : $R = -0.23^{+0.40}_{-0.32}$

ZEUS : consistent with $R = 0$, i.e. $J^P = 1^+$

does not contradict to $R = -1$

expected for $J^P = 1^-,\ 2^+$

Backup: fragmentation fractions for excited D mesons

Using world average for $f(c \to D^{*+})$:

	$f(c \to D_1^0)$ [%]	$f(c \to D_2^{*0})$ [%]	$f(c \to D_{s1}^+)$ [%]
ZEUS (prel.)	$1.46 \pm 0.18^{+0.33}_{-0.27} \pm 0.06$	$2.00 \pm 0.58^{+1.40}_{-0.48} \pm 0.41$	$1.24 \pm 0.18^{+0.08}_{-0.06} \pm 0.14$
CLEO	1.8 ± 0.3	1.9 ± 0.3	
OPAL	2.1 ± 0.8	5.2 ± 2.6	$1.6 \pm 0.4 \pm 0.3$
ALEPH	1.6 ± 0.5	4.7 ± 1.0	$0.94 \pm 0.22 \pm 0.07$
DELPHI	1.9 ± 0.4	4.7 ± 1.3	

1) the same amounts of excited D mesons in e^+e^- and ep data

2) situation with $f(c \to D_2^{*0})$ is not clear

3) $f(c \to D_{s1}^+)$ is twice as large as the expectation :

$\gamma_s \times f(c \to D_1^0) \approx 0.3 \times 2\% = 0.6\%$ **Why ?**

Backup: trigger selection

First level trigger:

CAL-FLT: regional energy sums

CTD-FLT: "tracks" looking to the nominal interaction point

DIS : scattered electron (and CTD-FLT)

Untagged PhP : CTD-CAL and CTD-FLT

Tagged PhP : 44m and 35m taggers, CTD-CAL and CTD-FLT

Second level trigger:

DIS : scattered electron and CAL energies

Untagged PhP : CAL energies and SLT tracks (high-W)

Tagged PhP : 44/35m taggers, CAL energies and SLT tracks

Third level trigger:

Inclusive DIS : almost offline selection

$D^{*\pm}$ in DIS : reconstructed $D^{*\pm}$ in DIS events (low Q^2)

Inclusive PhP : dijet events

$D^{*\pm}$ in PhP : reconstructed $D^{*\pm}$ in tagged/untagged PhP events