Evidence for a narrow anti-charmed baryon state

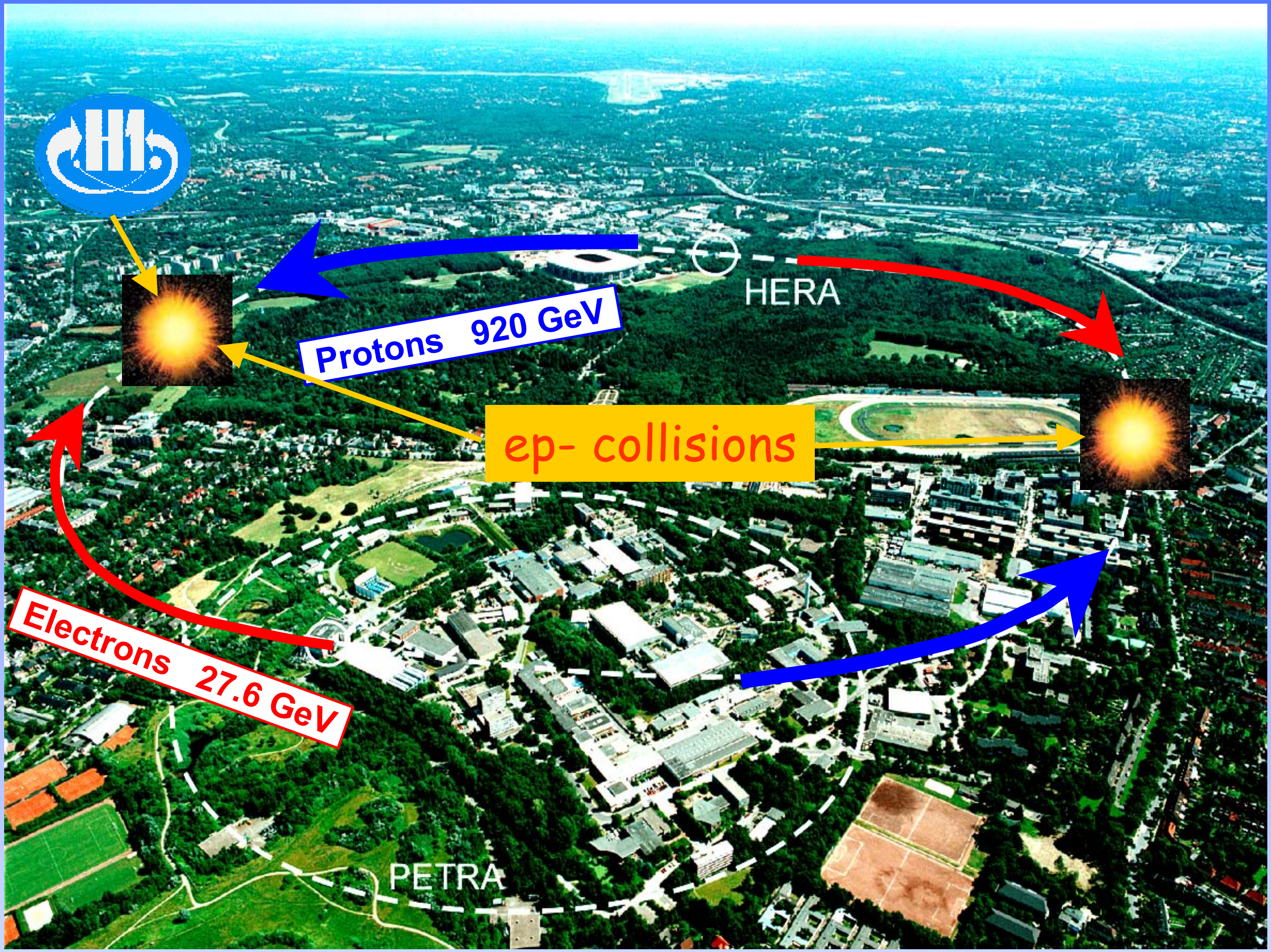
Karin Daum – Wuppertal

on behalf of

Outline:

- HERA & Deep inelastic scattering
- Charm production at HERA
- Search for an anti-charmed baryon with H1
- Signal checks and signal assessment
- Summary of Θ_c searches
- Conclusions

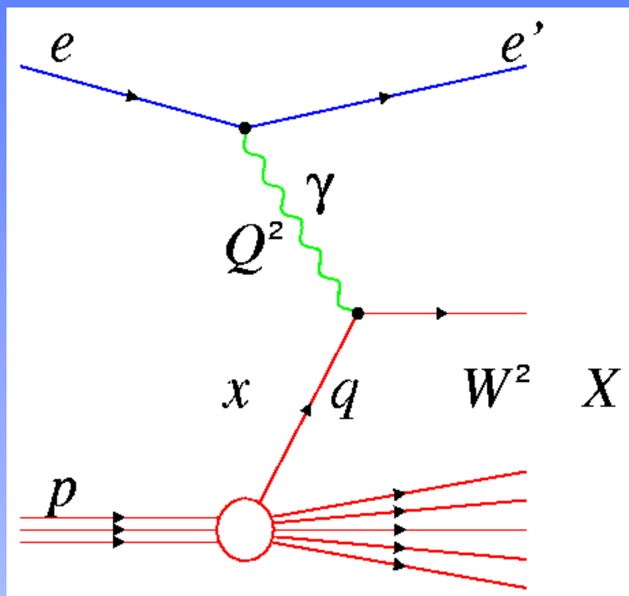
The HERA accelerator

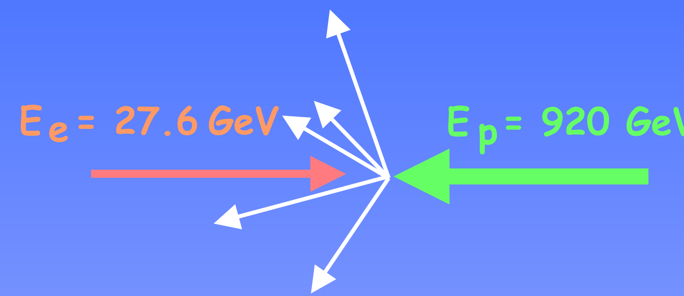


DESY
Hamburg
Germany

$\sqrt{s}$ ~ 300 - 320 GeV

HERA kinematics in ep collisions





$\sqrt{s}$ ~ 300-318 GeV (energy c.m.)

DIS kinematics:

Photon virtuality	$Q^2=-q^2$
Electron inelasticity	y
Scaling variable	x
Hadronic mass	W

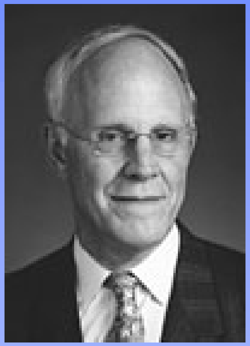
Kinematic regimes

Scattered e detected:	$Q^2 > 1$ GeV	Electroproduction (DIS)
Scattered e not detected:	$Q^2 \sim 0$ GeV	Photoproduction

In the focus of HERA: Strong interactions

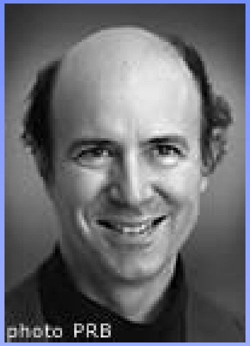
HERA is <u>the</u> machine
for precision measurements/tests of strong interactions (QCD)

Nobel Prize 2004



David J. Gross

H. David Politzer



Frank Wilczek

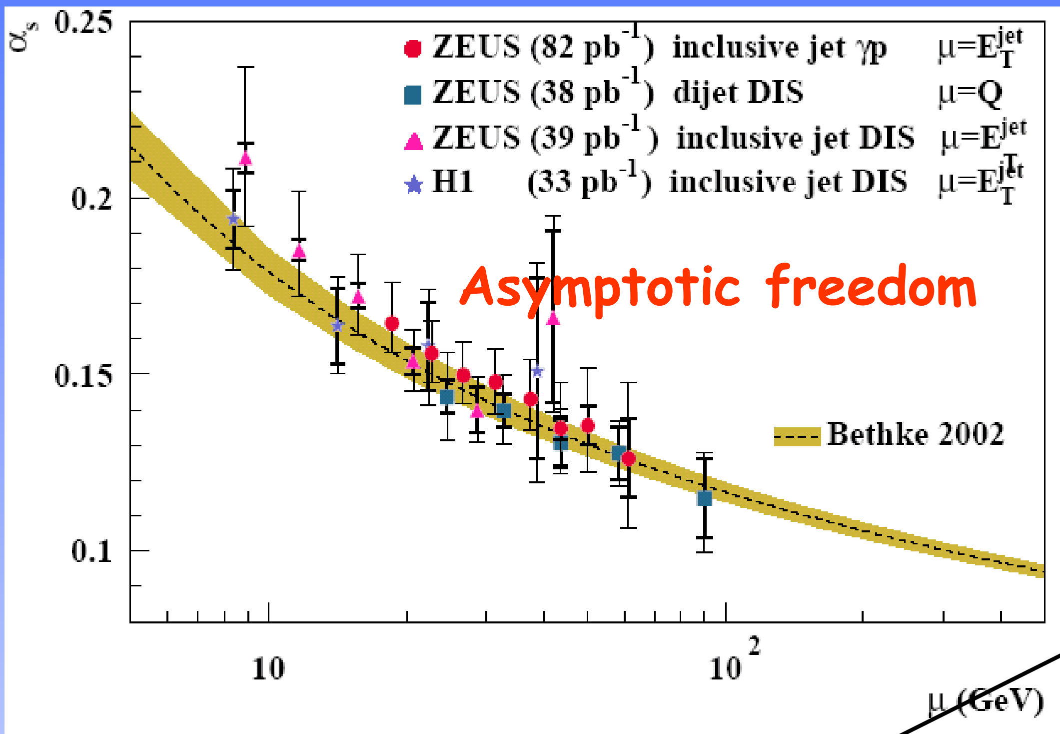
RGE has negative β

Gluon self coupling $\Rightarrow$ Asymptotic freedom

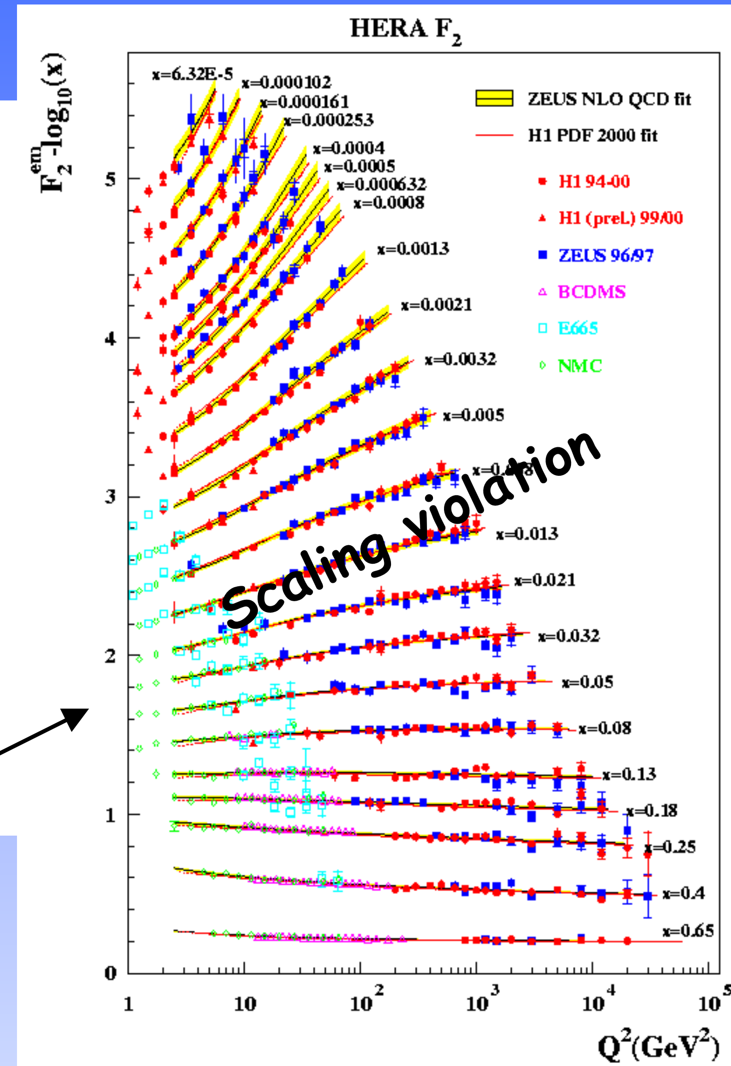
Gluon emission $\Rightarrow$ Scaling violation

Physics at HERA (I)

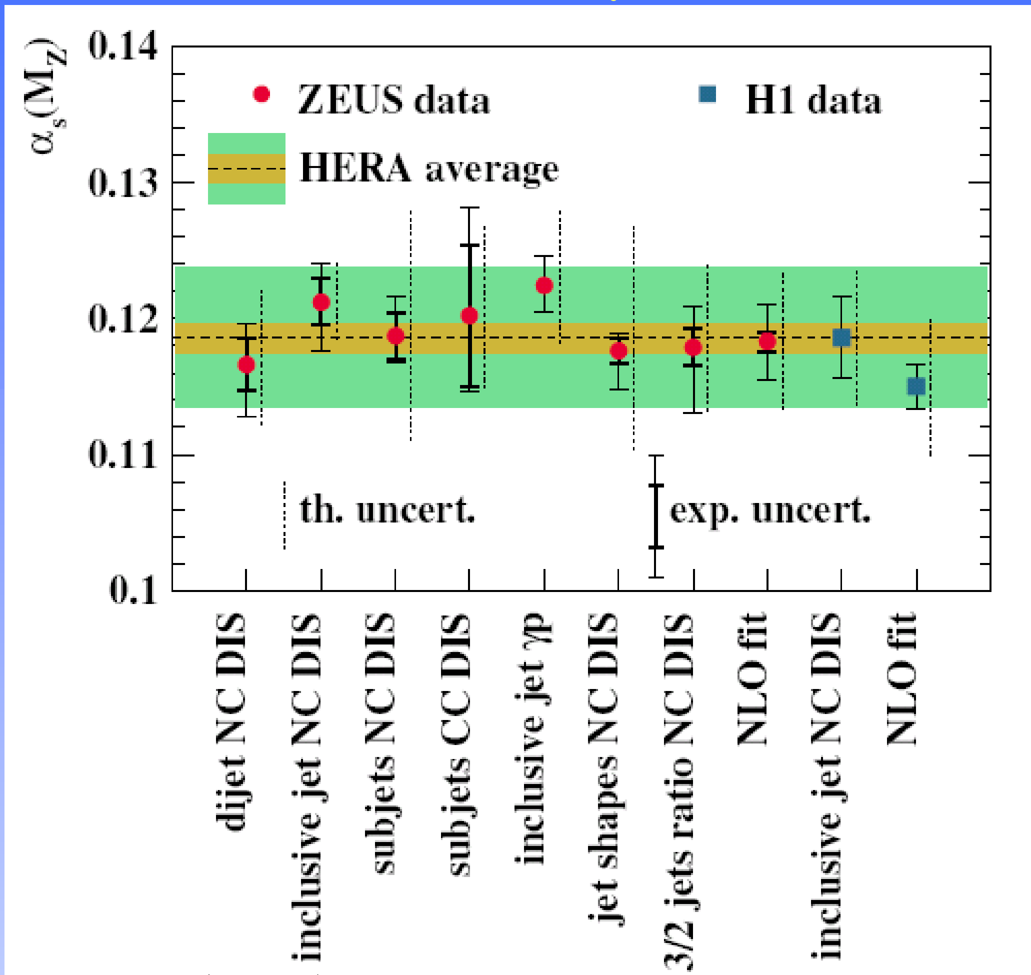
Strong coupling constant α_s at Hera

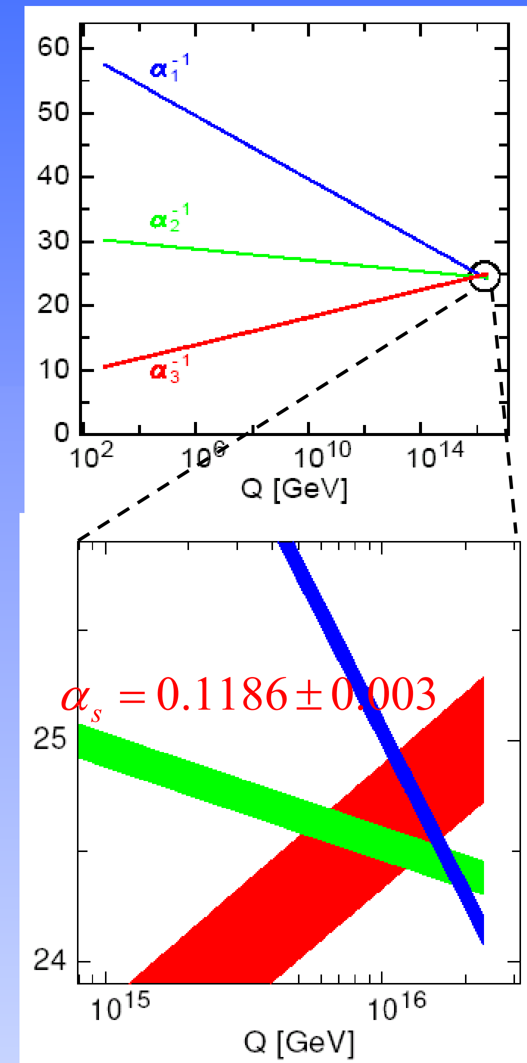


Proton structure function



Physics at HERA (II)



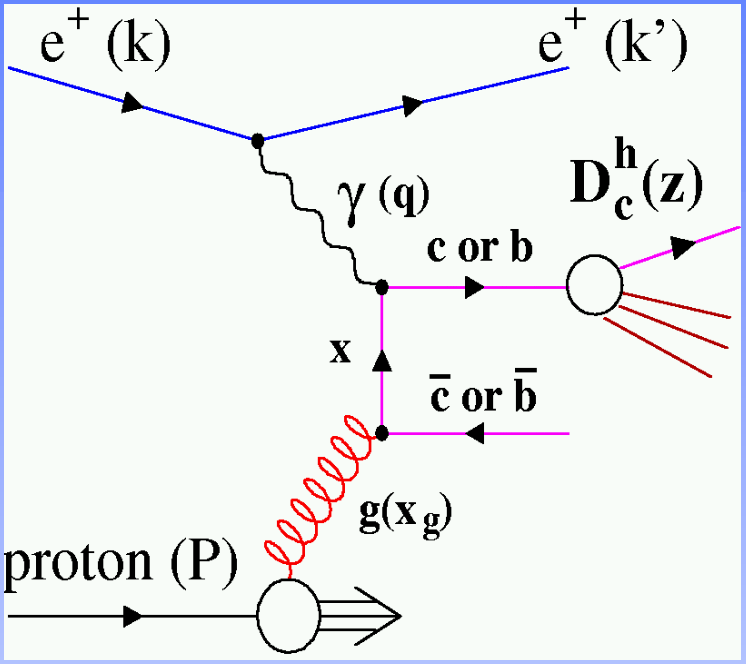


HERA(prel.)

$$\alpha_s(M_Z^2) = 0.1186 \pm 0.0011(\text{exp}) \pm 0.005(\text{thy})$$

hep-ph/0407067 B.Allanach … P.Zerwas

Charm physics at HERA (I)



Heavy quark mass:

Charm is not a constituent of the proton

copious production from gluonsin the proton

⇓

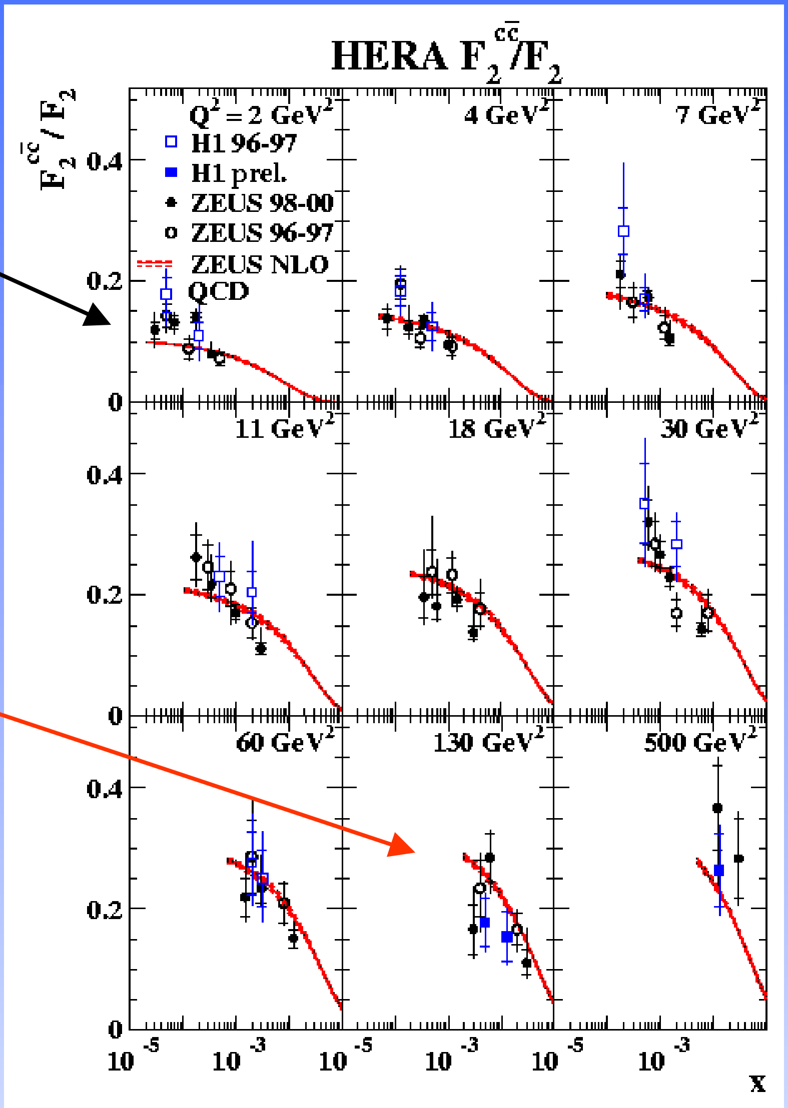
charm production is dominated By Boson Gluon Fusion (BGF)*

$$\gamma g \rightarrow c\bar{c}\ (b\bar{b})$$

* LO QCD

Charm physics at HERA (II)

Charm contribution to
The total cross section



rises up to ~ 30 % at large Q²

HERA is a charm factory

Charmed pentaquark search

Inspired by the evidences for the strange pentaquark Θ^+ from K^+n and K^0_sp analyses

Why not a charmed pentaquark ?

Θ^+ formation may be due to features of the QCD vacuum (fragmentation process)

Universality of QCD vacuum *e.g.* flavour blind

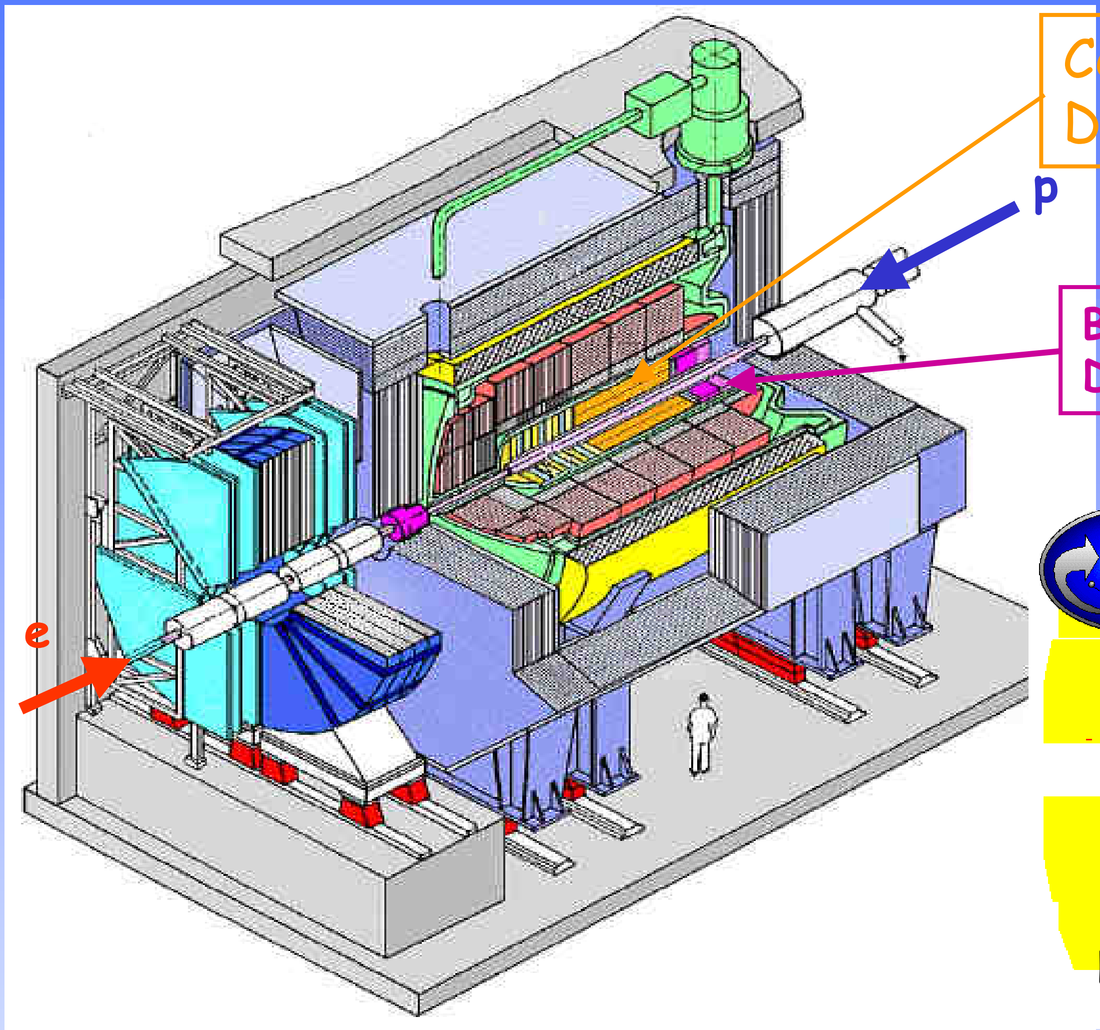
⇓

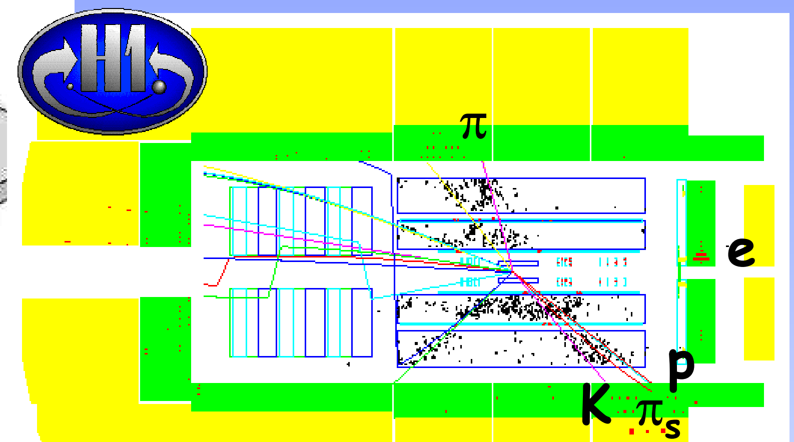
- Features of Θ_c similar to those of Θ^+ (i.e. Q-value, width)
- Similarities in fragmentation process of charmed hadrons

⇓

Search for Θ_c in $D^{*-}p$ (+c.c.)

The H1 detector





D*p event in DIS

D* Signal

Golden channel
$D^{*+} \rightarrow D^0 \pi_s \rightarrow (K\pi)\pi_s$
(low BR but clean signal)
$M(D^*)-M(D^0) = 145.4$ MeV
Q-value only 6 MeV

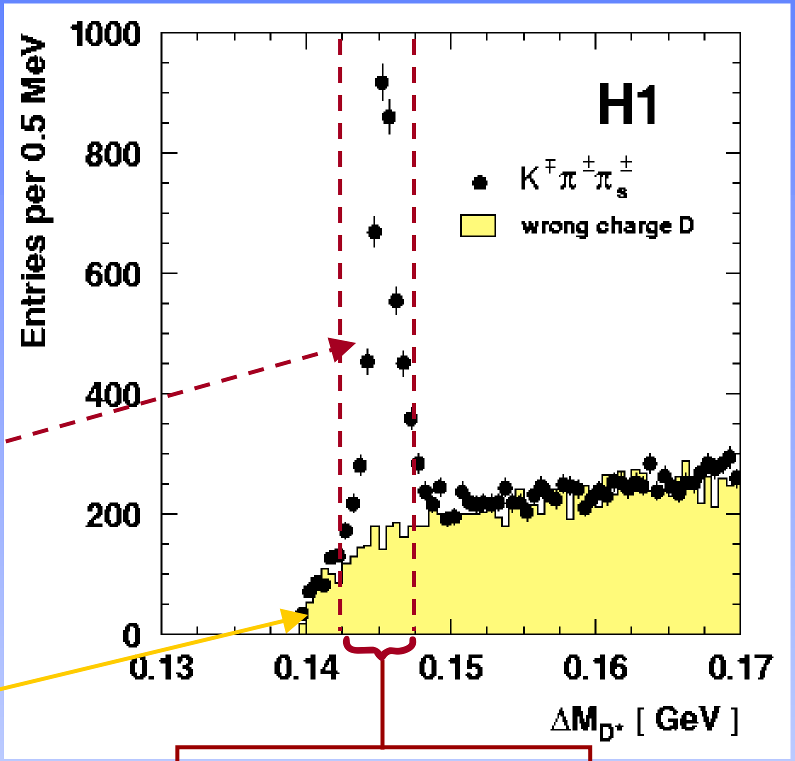
Mass difference technique:
$\Delta M_{D^*} = M(K\pi\pi_s) - M(K\pi)$

Good Signal/Background

3400 D*'s in DIS to start with

Non charm induced background
"wrong charge D" :
fake D^0 $(K^+\pi^+ / K^-\pi^-)+\pi_s$

96-00 data 75 pb^{-1} DIS: $Q^2>1$ GeV^2

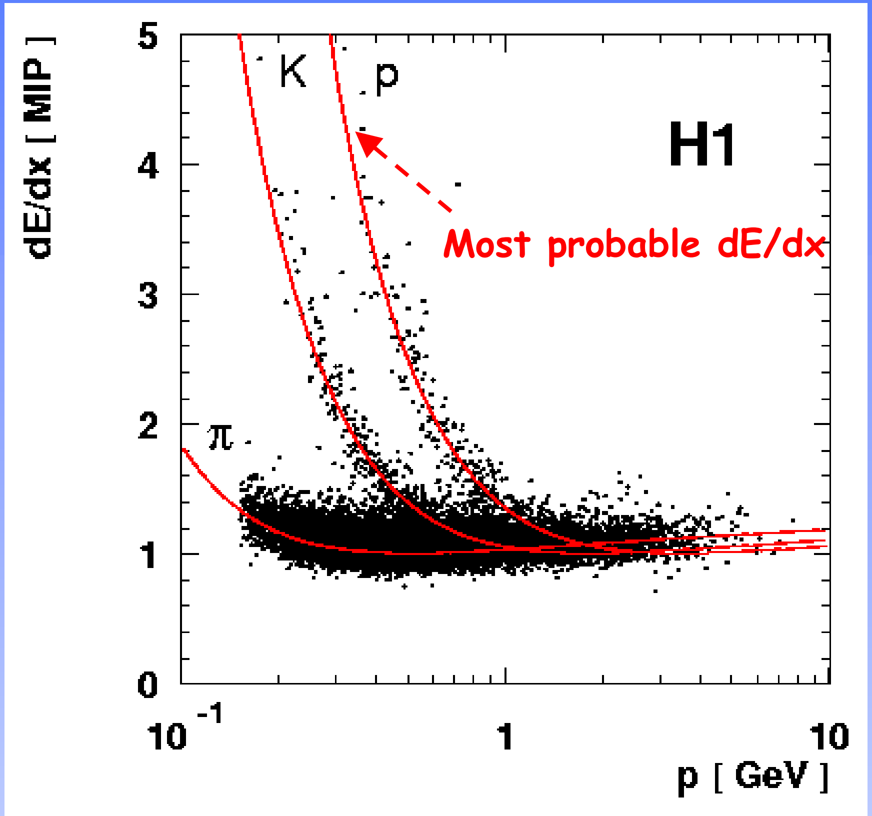


D* signal region subsequently used

Proton selection

Particle identification via dE/dx

- 3-5% accuracy
- 8% MIP resolution



Use dE/dx for background suppression

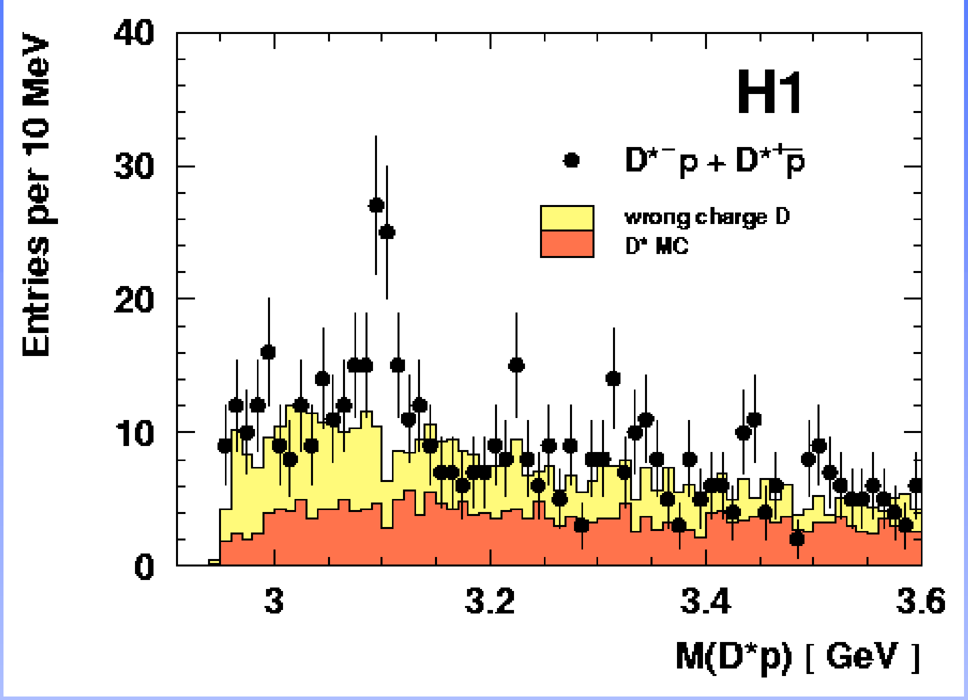
Opposite sign D*p mass distribution

Apply mass difference technique

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

- no enhancement in D* Monte Carlo
- no enhancement in wrong charge D

Background well described by D* MC and "wrong charge D" from data

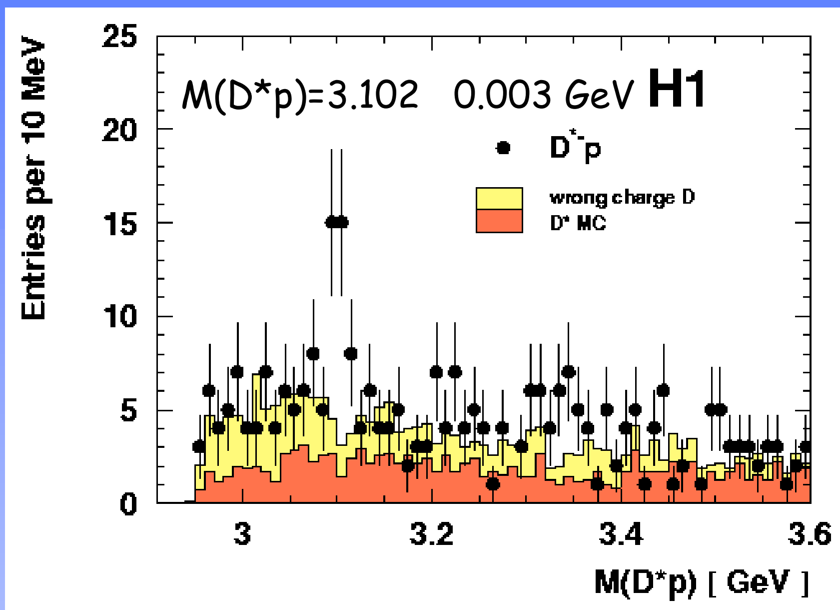


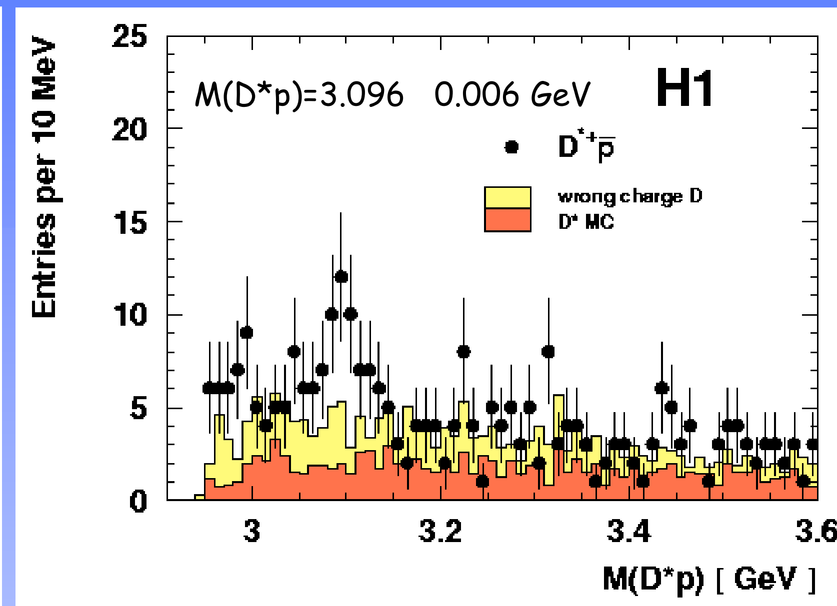
narrow resonance at M=3099± 3(stat.) ± 5 (syst.) MeV

- signal visible in different data taking periods

Signal in both $D^{*-}p$ and in $D^{*+}\bar{p}$

$M(D^*p) = m(K\pi\pi p) - m(K\pi\pi) + m(D^*)$





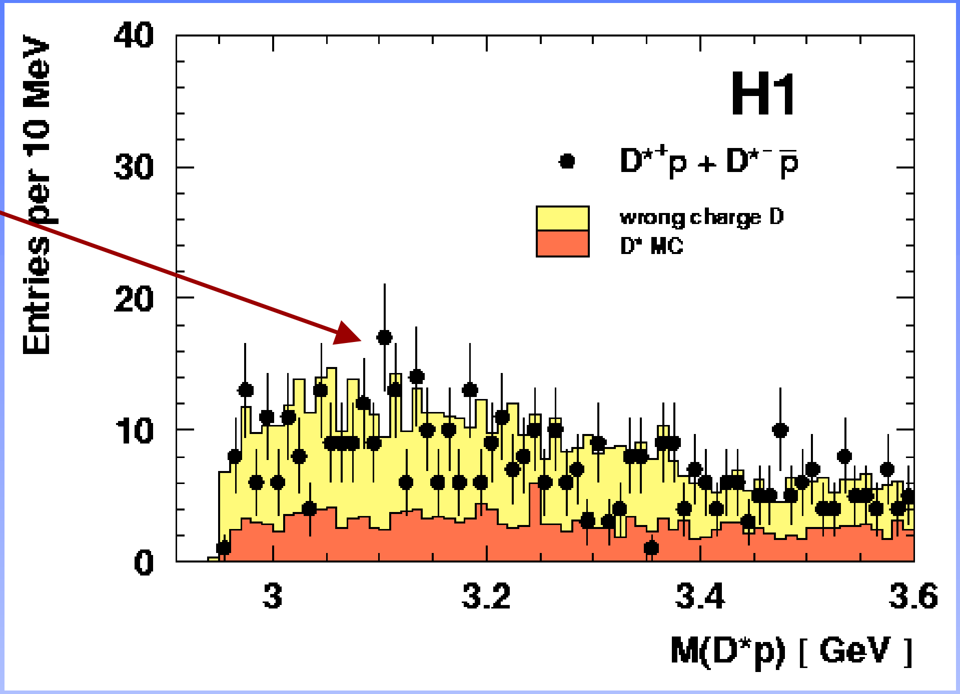
25.8 ± 7.1 *Events*

23.4 ± 8.6 *Events*

Signal of similar strength observed for both charge combinations at compatible M(D*p)

Signal in like sign D*p combinations?

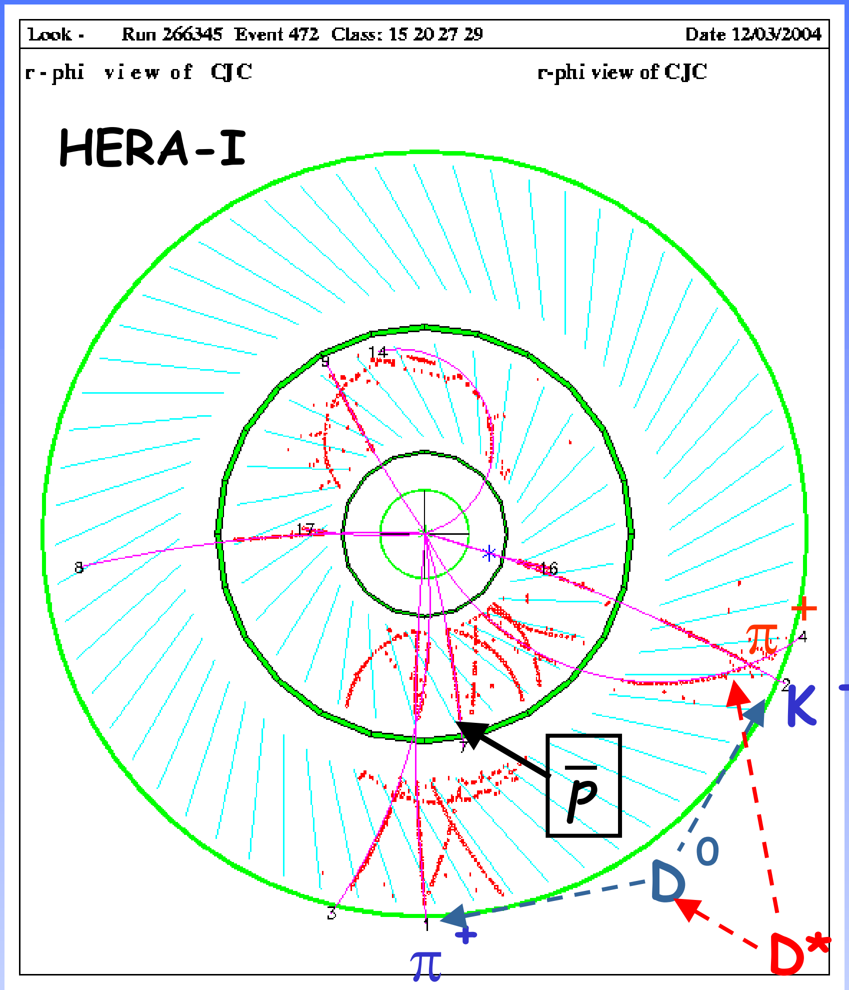
No significant peak in like sign D*p

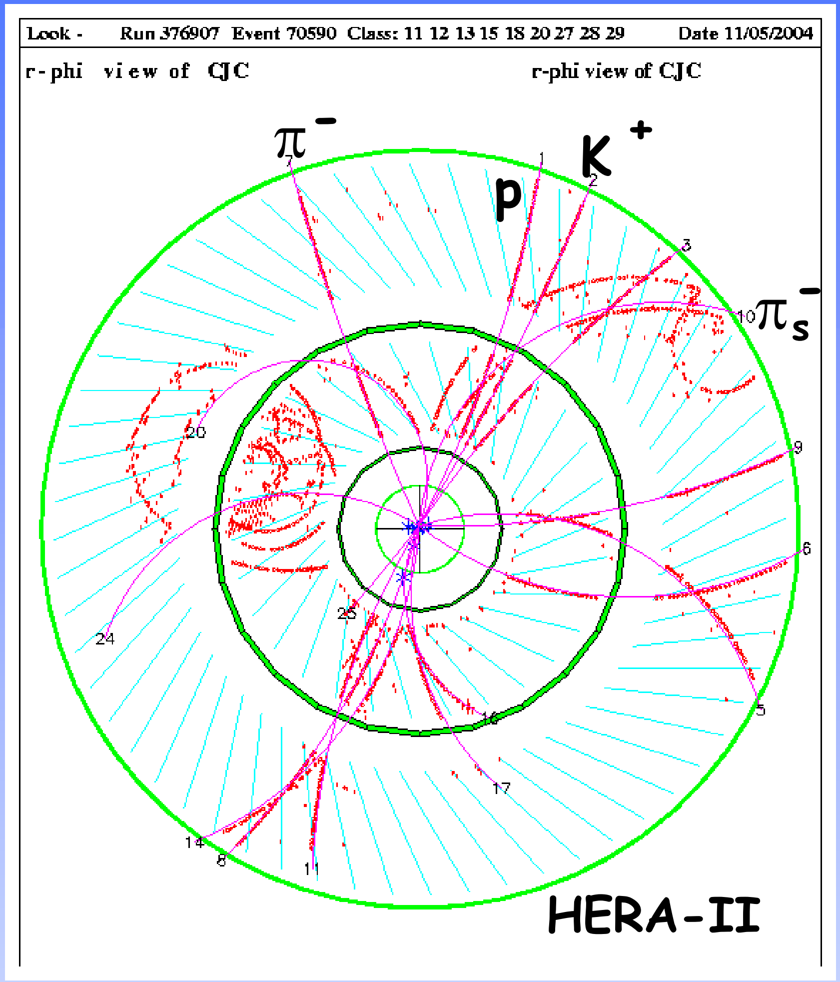


Reasonably described by D* MC and wrong charge D from data

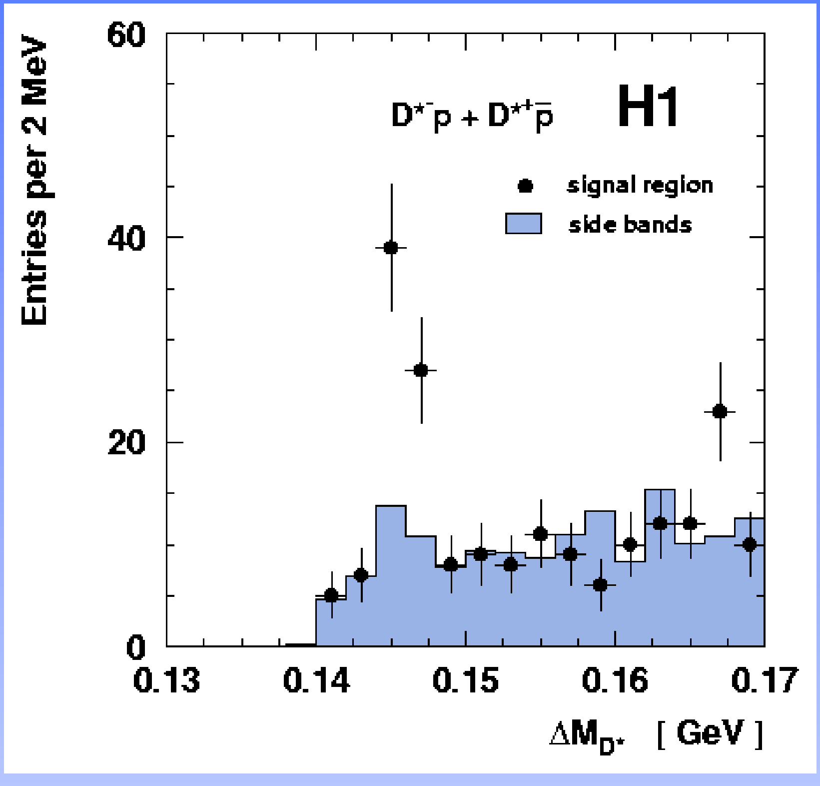
No

Typical D*p candidates

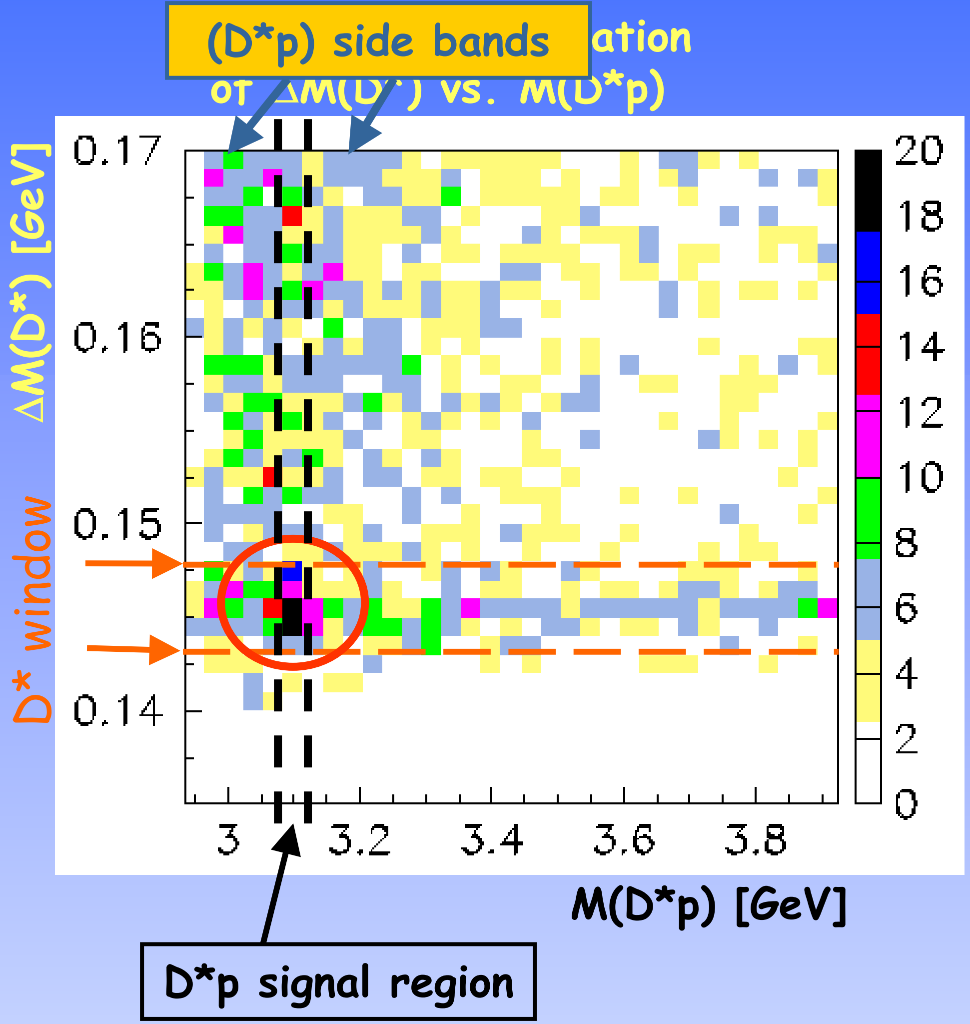




Does the resonance come from D*'s?

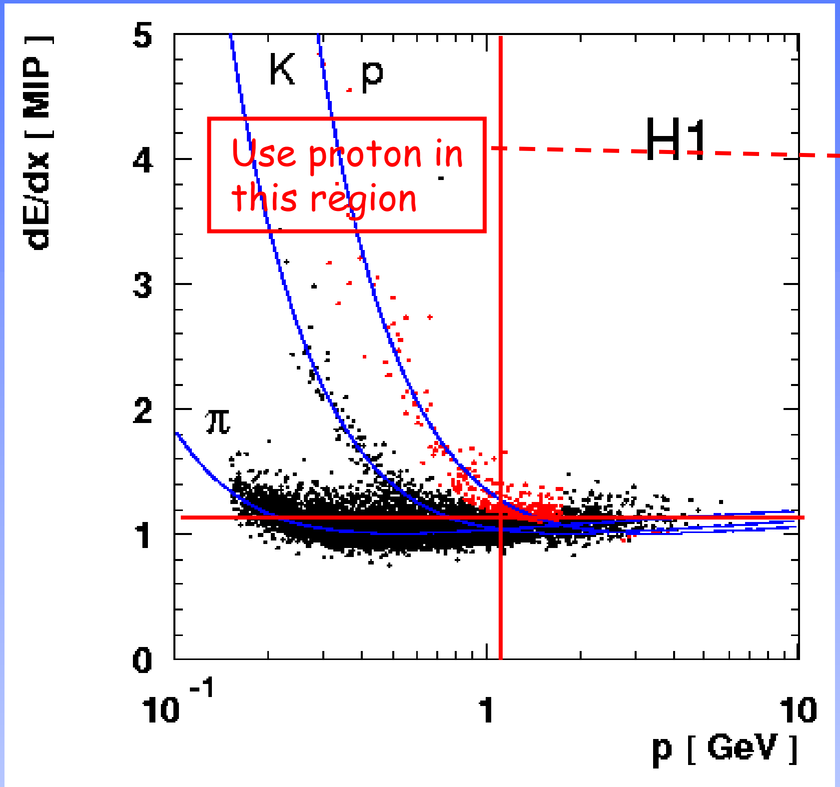


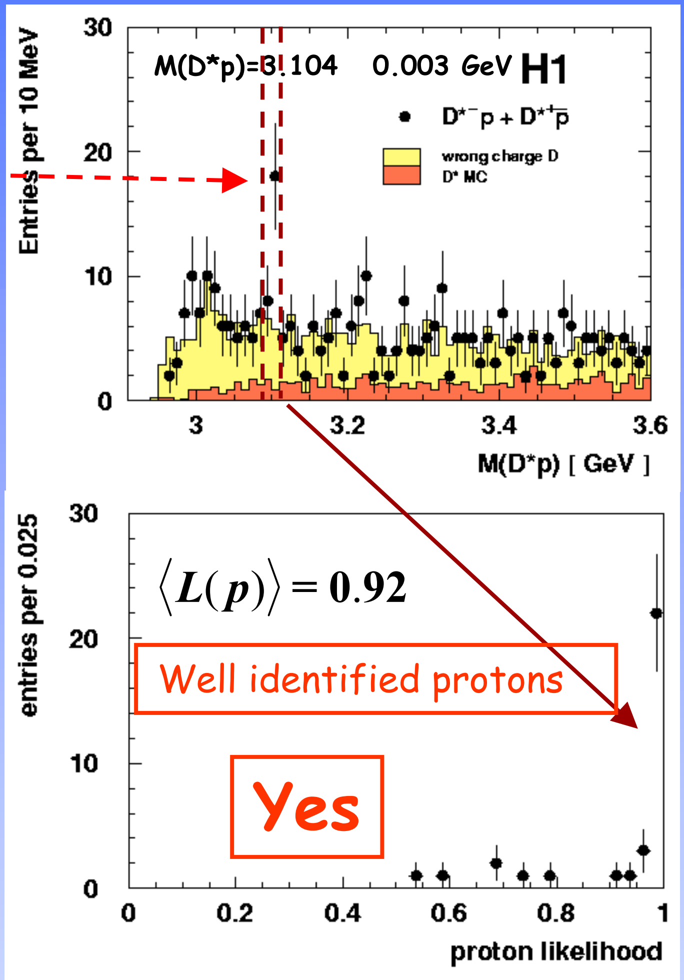
Side band scaled to the width of the signal window in M(D*p)



→ the (D*p) signal region is richer in D*

Is the D*⁻p[1)] signal due to protons?





M(D*p) = m(Kππp)-m(Kππ)+m(D*) $_{PDG}$

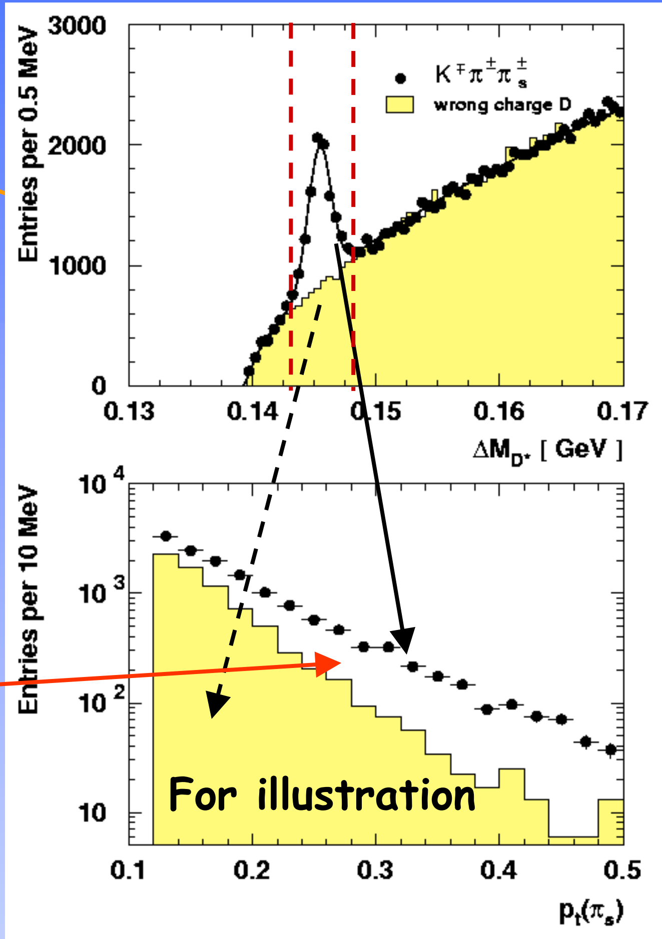
1) Charge conjugate always implied

Physics changes on-resonance ?

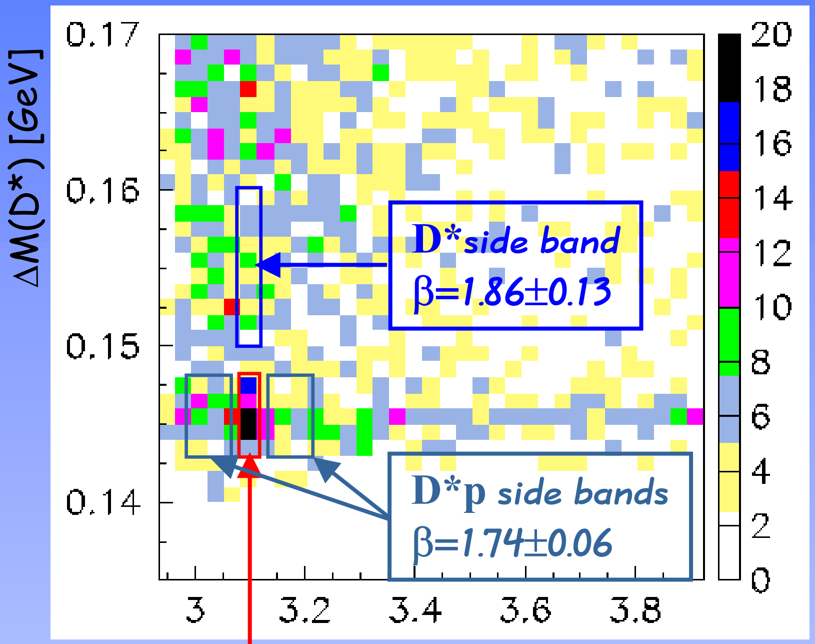
- Single particle momentum spectra are steeply falling
$\rightarrow$This feature is preserved in the combinatorial background of invariant mass analyses

Harder spectrum for particles from decay due to mass release

Harder spectrum for particles from decay of charmed hadrons due to hard charm fragmentation



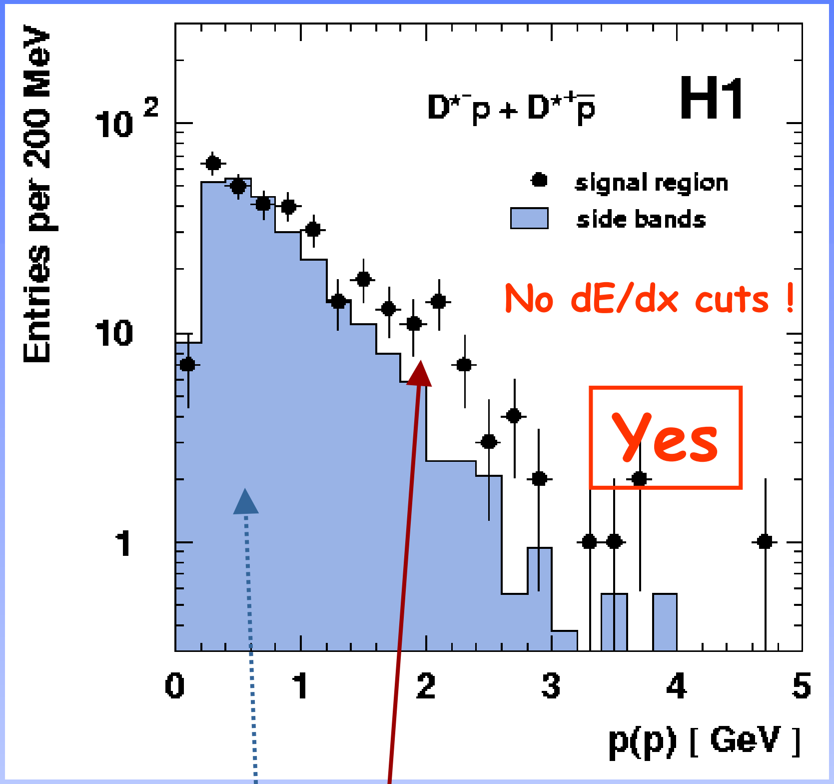
Physics changes on-resonance ?



Signal region
$\beta=1.27\pm0.09$

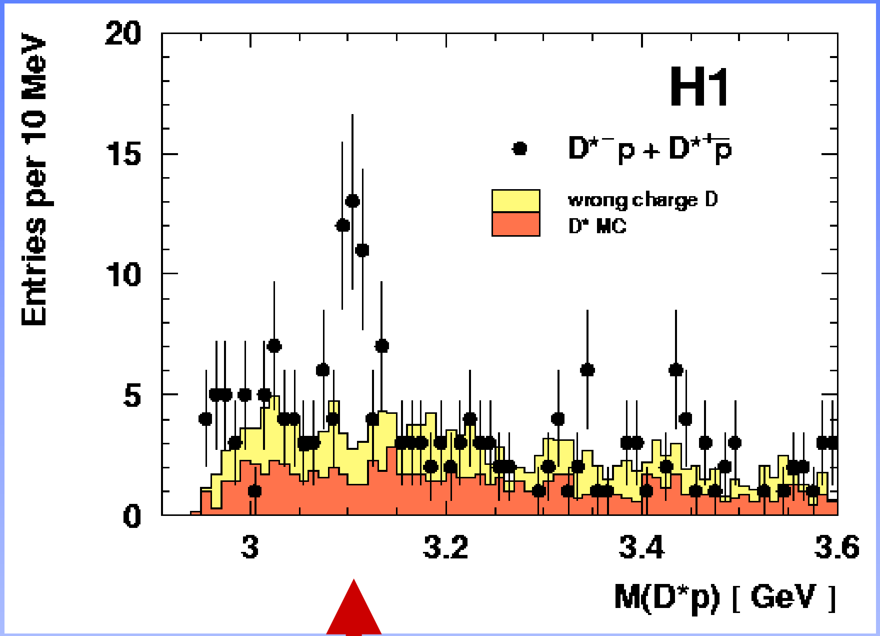
M(D*p) [GeV]

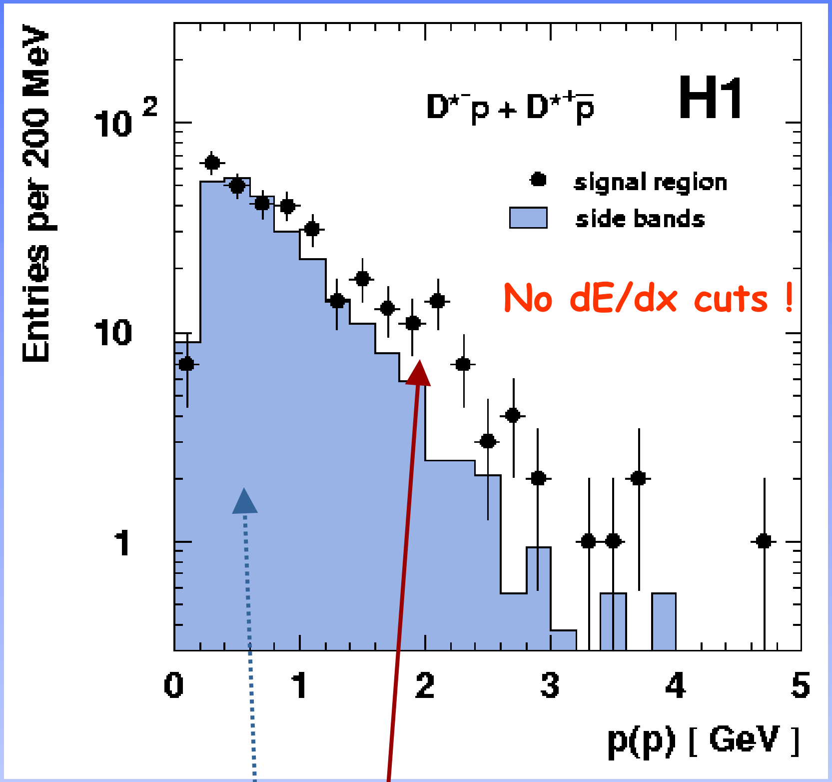
Fit slope with $\alpha \cdot \exp\{-\beta p(p)\}$



The momentum spectrum of the particles in the signal region is harder than in the M(D*p) side bands

Physics changes on-resonance ?





At large p(p) (>2 GeV)
Signal clearly visible
without dE/dx

The momentum spectrum of the particles in the signal region is harder than in the M(D*p) side bands

Kinematic tests

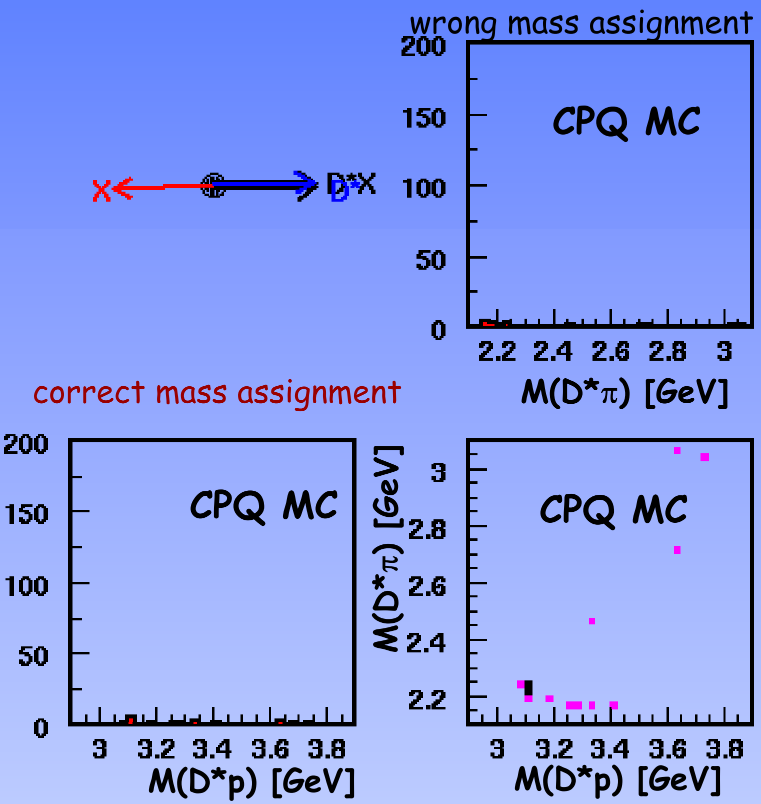
2-Body Decay

$$M^2 = (P_1 + P_2)^2$$

$$= (m_{D*}^2 + m_X^2 + 2E_{D*}E_X - 2\vec{p}_{D*}\vec{p}_X)$$

Mass M independent of decay angle Θ* only for correct mass assignment

Monte Carlo expectation



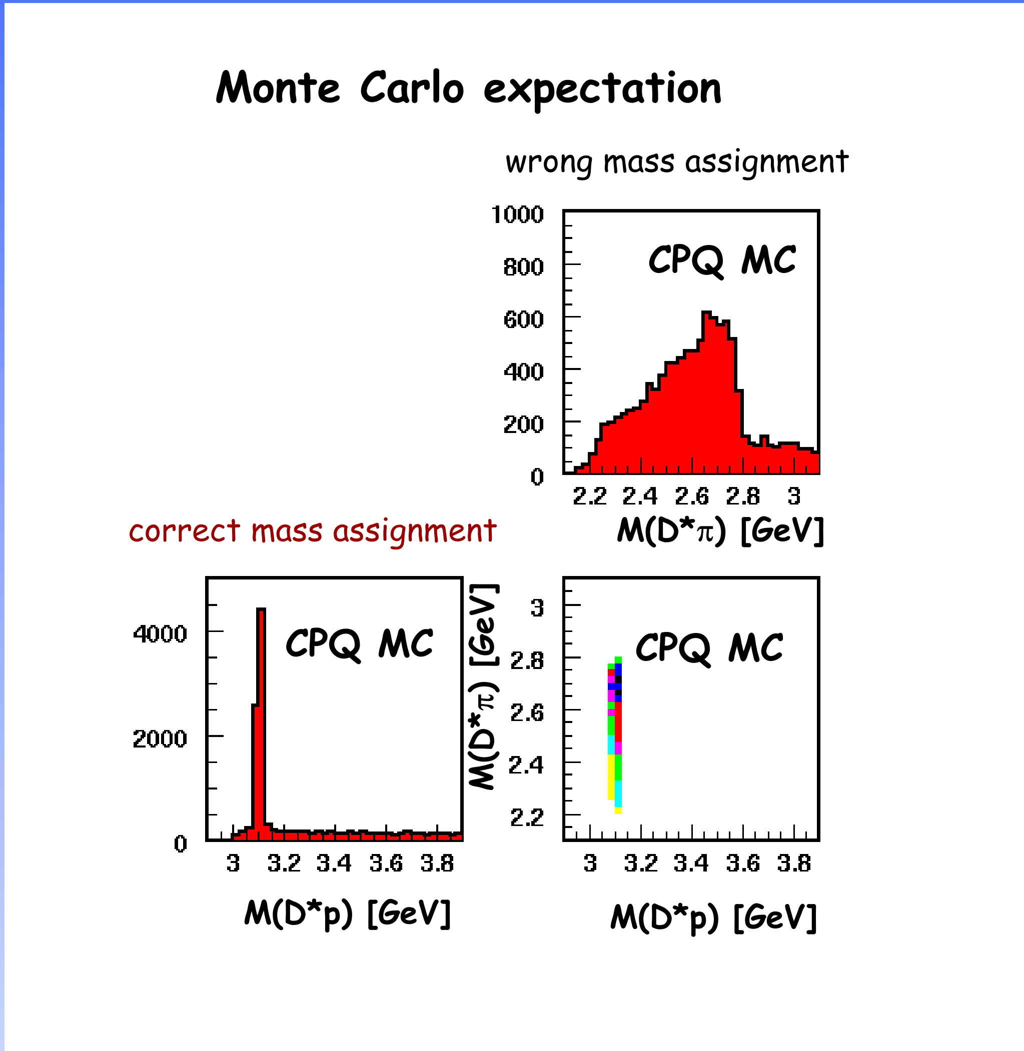
Kinematic tests

2-Body Decay

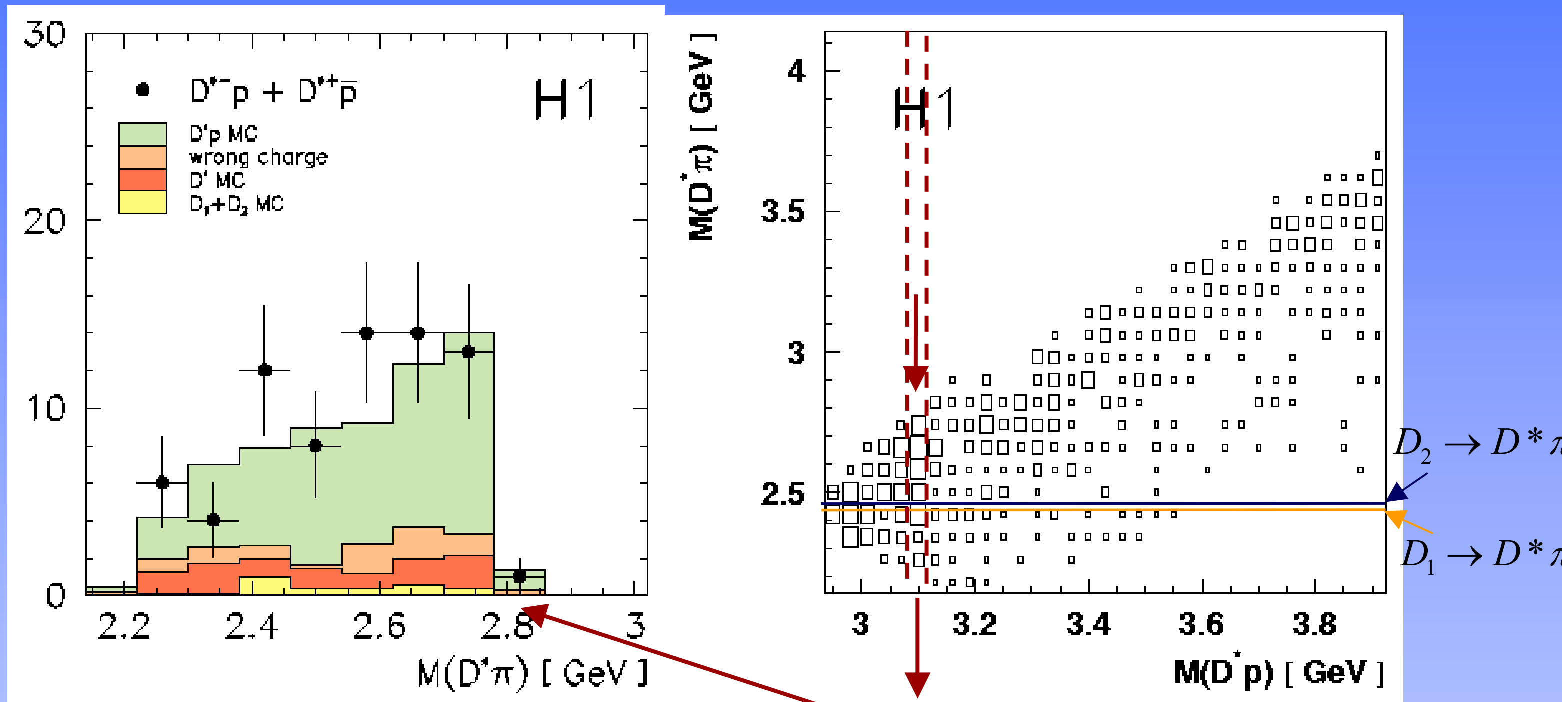
$$M^2 = (P_1 + P_2)^2$$
$$= (m_{D*}^2 + m_X^2 + 2E_{D*}E_X - 2\vec{p}_{D*}\vec{p}_X)$$

Mass M independent of decay angle Θ* only for correct mass assignment

Band like structure visible in the M(D*p)-M(D*x) plane in data?



Kinematic test: D*p vs. D*π



Go to the D*p signal region and look at D*π

π-mass hypothesis excluded from the shape and range of D*π mass distribution !

D*p in photo-production

- total: 4900 D* to start
- D*p peak at the same mass in γp
- no enhancement in non-charm bg
- 95 % bg due to non-charm

Background well described by wrong charge D from data

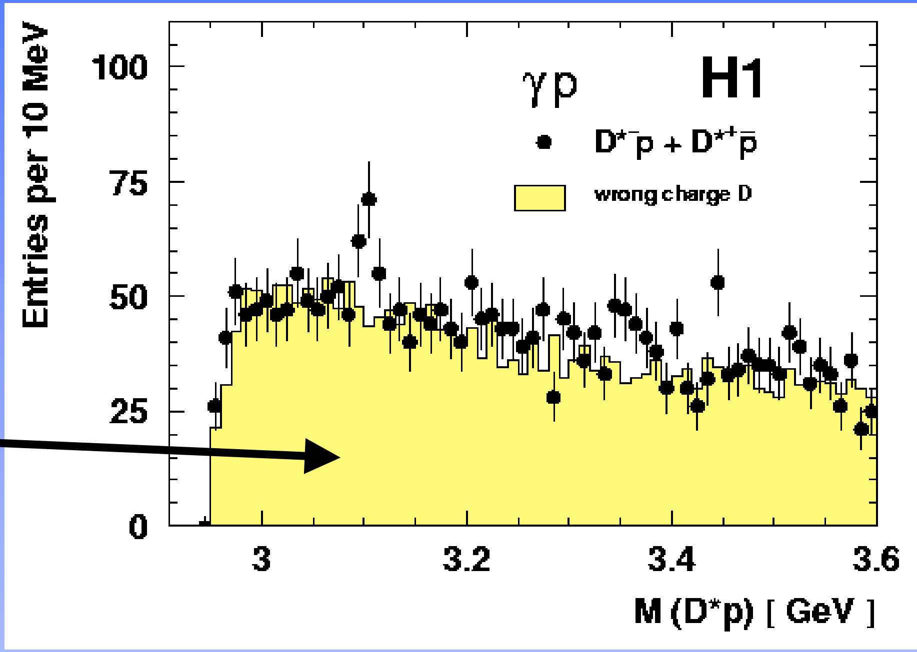
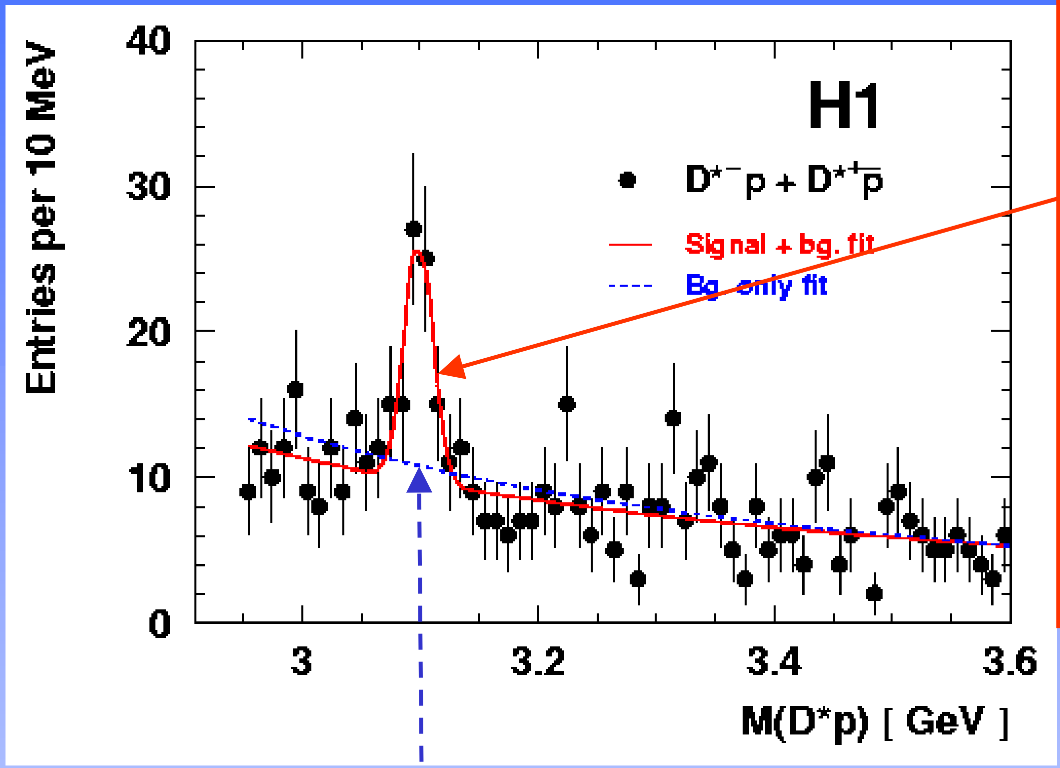


Photo-production more difficult due to large non-charm background

but

independent confirmation of the signal

Significance estimate



signal+background fit:

mass:
3099 ± 3(stat) ± 5(syst.) MeV
width: 12 ± 3 MeV
(cons. with exp. Resolution)

Numbers of signal and bgr
N_b=45.0 ± 2.8
(within ± 2σ =± 24MeV)
N_s=50.6 ±11.2
(1.46 ± 0.32 % of D* yield, uncorrected in acceptance)

For significance estimate:
Fit background only hypothesis
N_b=51.7 +- 2.7
Events in signal region: 95

Background fluctuation probability (52 → 95) :
4×10^{-8} (Poisson)
5.4 σ (Gauss)

Difference in likelihood of background and signal+background fit: $\sqrt{2\Delta \log \mathcal{L}}$ = 6.2σ
(Test independent of peak position)

Results of θ_c searches

H1 observation in $ep \to c\bar{c}\,X$

$R(\Theta_c \to D^*p/D^*) = 1.46 \pm 0.32\ \%$ (uncorrected)

prelim.

Negative results for θ_c from:

ALEPH	$e^+e^- \to Z^0 \to c\bar{c}$
FOCUS	$\gamma N \to c\bar{c}\,X$
CDF	$p\bar{p} \to c\bar{c}\,X$
BELLE	$e^+e^- \to \Upsilon(4s) \to B^0\bar{B}^0$

Not contradicting H1

$B(B^0 \to \Theta_c p\pi) \times B(\Theta_c \to D^*p) /\ B(\Theta_c \to D^*pp\pi) < 11\%$ @ 90% C.L.

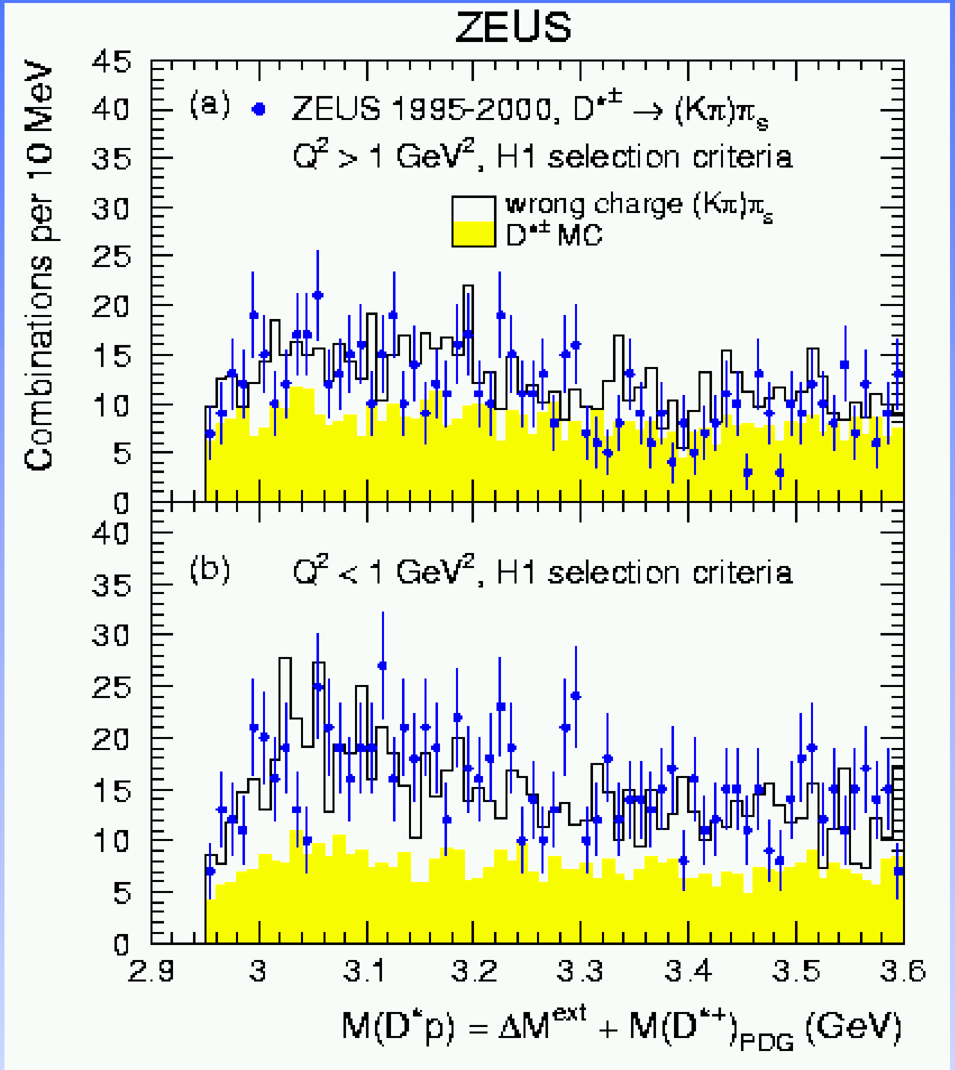
ZEUS $ep \to c\bar{c}\,X$

Different physics processes investigated

Physics seen by ZEUS should be directly comparable to H1

Search for charmed PQ, $\theta_c \to D^*p$, in ZEUS

1995-2000 data, 127 pb^{-1}
Selection of D*, p close to H1 cuts



DIS (Q^2>1 GeV): 5920±90 D*'s
γp (Q^2<1 GeV):11670±140 D*'s

No signal seen in D*p

Limits on Θ_c/D* for DIS:

$R(\Theta_c \to D^*p/D^*) < 0.51\%$ @95% C.L.

- Includes some systematic uncertainties
- But selection different from H1
- Assumes production mechanism of Θ_c to be the same as for D*

H1 vs. ZEUS observation – What does it mean?

H1: $R(\Theta_c \to D^*p/D^*) = 1.46 \pm 0.32$ % in DIS observed **prelim.**

ZEUS $R(\Theta_c \to D^*p/D^*) < 0.51\%$ @ 95% C.L. in DIS with corrections

⇒Numbers are not consistent, but

- different selection
- different triggers:

ZEUS	**DIS events:**	**only ~40% are from the DIS trigger**
H1	**DIS events:**	**100% are from the DIS trigger**

⇒ different phase space explored by H1 and ZEUS

Θ_c and D* production mechanism may be different at HERA

(as suggested by the Θ^+/K^0_s yields observed by ZEUS)

⇒ We have to understand more about Θ_c production

Conclusions

- Evidence for a neutral anti-charmed baryon state decaying to D*p in deep inelastic scattering from H1
  - Signal due to D* mesons and protons
  - Harder proton spectrum in the signal region as expected for secondaries from the decay of charmed hadrons
  - Kinematic tests agree only with the D*p hypothesis
  - Independent confirmation from photo-production
- Poissonian background fluctuation probability $<4\cdot10^{-8}$
- Searches from ZEUS for D*p yield negative results

$\Downarrow$

Situation unclear – more understanding of D*p production dynamics needed

Backup Slides

Remarks on ALEPH

$R_b \approx 22\%$, $R_c \approx 17\%$

D* @ LEP are produced predominantly by beauty

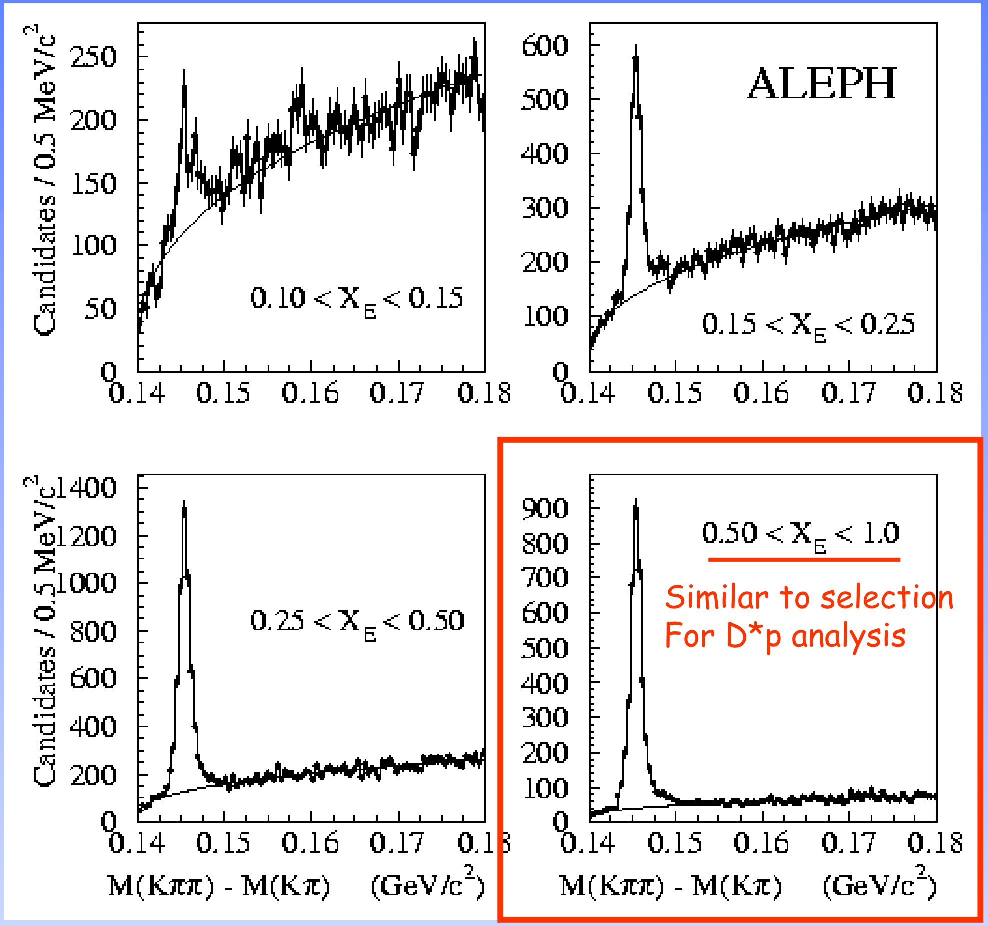
$\langle x_E \rangle_{cc} \approx 0.488$

In case of $\Theta_c \rightarrow D^*p$:
$\langle x_E \rangle_{cc} \approx 0.32$

D* selection may not be appropriate for Θ_c
Likely that possible Θ_c is cut out by D* selection

No Θ_c Monte Carlo used for $\Theta_c \rightarrow D^*p/D^*$ yields

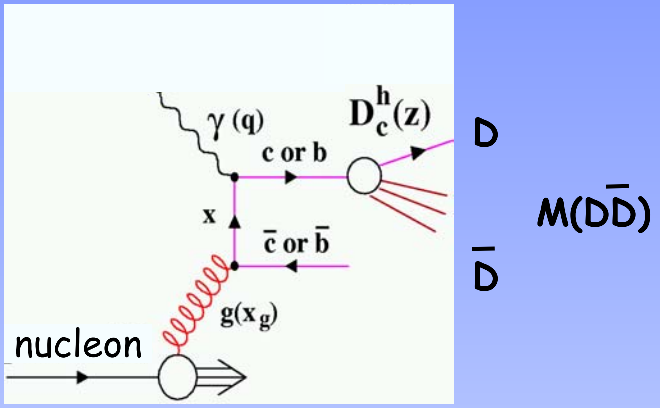
D* signals for different x_E

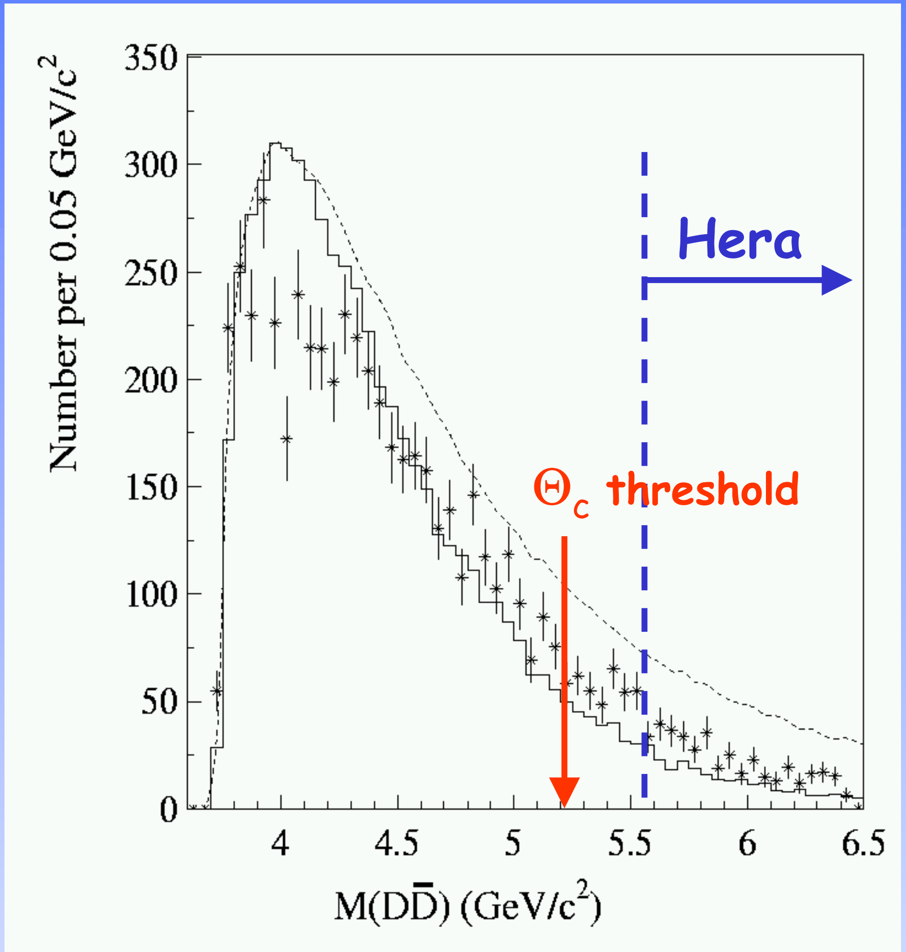


Remarks on FOCUS

Fixed target experiment
180 GeV photons on ^{9}Be
$\rightarrow$hadronic mass W~18 GeV

Hera: 60<W<280 GeV





Large phase space suppression for Θ_c in FOCUS
No Monte Carlo used by FOCUS

Remarks on CDF

Charm production via gluon gluon fusion
Similar to BGF at HERA
Depends quadratically on the gluon density

No details on the analysis obtainable e.g.
effect of trigger
D* selection ...

CDF used a Monte Carlo for Θ_c signal estimation but
model completely wrong: elastic J/Ψ production decaying to D*p

Remarks on e^+e^- data

- Production baryons and light nuclei in high energy processes not understood

e.g. anti-deuteron production:

H1 γp:	$\bar{d}/\bar{p} = (5.0 \pm 1.0 \pm 0.5) \cdot 10^{-4}$
RHIC Au-Au:	$\bar{d}/\bar{p} = 2 \cdot 10^{-3}$
LEP e^+e^-:	$\bar{d}/\bar{p} < 1.6 \cdot 10^{-4}$

Anti-deuteron production (6 quarks) strongly process dependent

Could be similar for pentaquarks

Possible signature of the charmed pentaquark

Common belief:
$\Theta_c \rightarrow \bar{D}\, p$
(pseudo-scalar D meson)

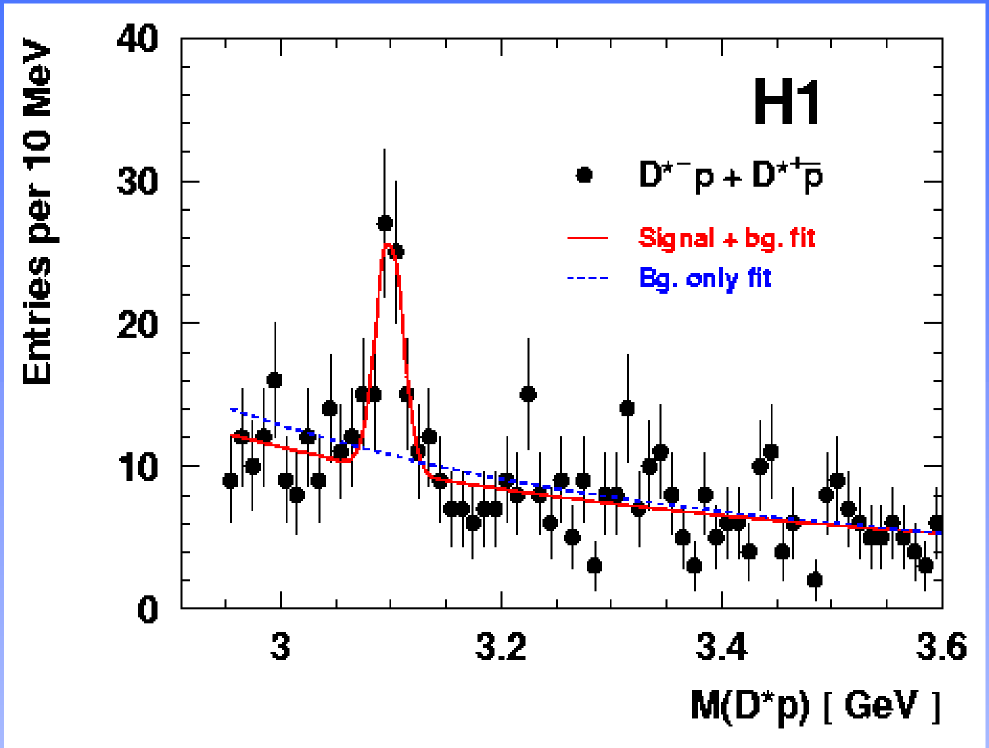
Vector mesons not suppressed

Charm fragmentation fractions

$f(c \to D^+)$	γp	$0.248 \pm 0.014^{+0.004}_{-0.008}$
	DIS	$0.202 \pm 0.020^{+0.045+0.029}_{-0.033-0.021}$
	e^+e^-	0.232 ± 0.010
$f(c \to D^0)$	γp	$0.557 \pm 0.019^{+0.005}_{-0.013}$
	DIS	$0.658 \pm 0.054^{+0.117+0.086}_{-0.142-0.048}$
	e^+e^-	0.549 ± 0.023
$f(c \to D_s^+)$	γp	$0.107 \pm 0.009 \pm 0.005$
	DIS	$0.156 \pm 0.043^{+0.036+0.050}_{-0.035-0.046}$
	e^+e^-	0.101 ± 0.009
$f(c \to \Lambda_c^+)$	γp	$0.076 \pm 0.020^{+0.017}_{-0.001}$
	e^+e^-	0.076 ± 0.007
$f(c \to D^{*+})$	γp	$0.233 \pm 0.009^{+0.003}_{-0.005}$
	DIS	$0.263 \pm 0.019^{+0.056+0.031}_{-0.042-0.022}$
	e^+e^-	0.235 ± 0.007

But what is experimentally feasible ?

Details of fit



Charges	M[MeV]	σ[MeV]	N_S
$D^{*-}p + D^{*+}\bar{p}$	3099 ± 3	12 ± 3	50.6 ± 11.2
$D^{*-}p$	3102 ± 3	9 ± 3	25.8 ± 7.1
$D^{*+}\bar{p}$	3096 ± 6	13 ± 6	23.4 ± 8.6

All Checks (I)

check events

- signal events scanned visually: no anomalies
- double entries ?
  1.) Within +- 24 MeV around peak: 1 double entry
  2.) All M(D*p) < 3.6 GeV: 1.12 entries / event

signal from D*,p?

- backward D* analysis: signal region D* rich
- well identified protons (p<1.2, hard dE/dx): signal there
  average norm. likelihood in signal region $\langle L_p \rangle = 0.92$

physics in signal and bgr region?

- physics on/off resonance: proton spectrum harder on resonance

peak stable?

- signal present in subsamples (in Q^2, x, y, η, p_t, data taking period)
- variations of binning and selection: mass, width stable
- signal present in photoproduction

All Checks (II)

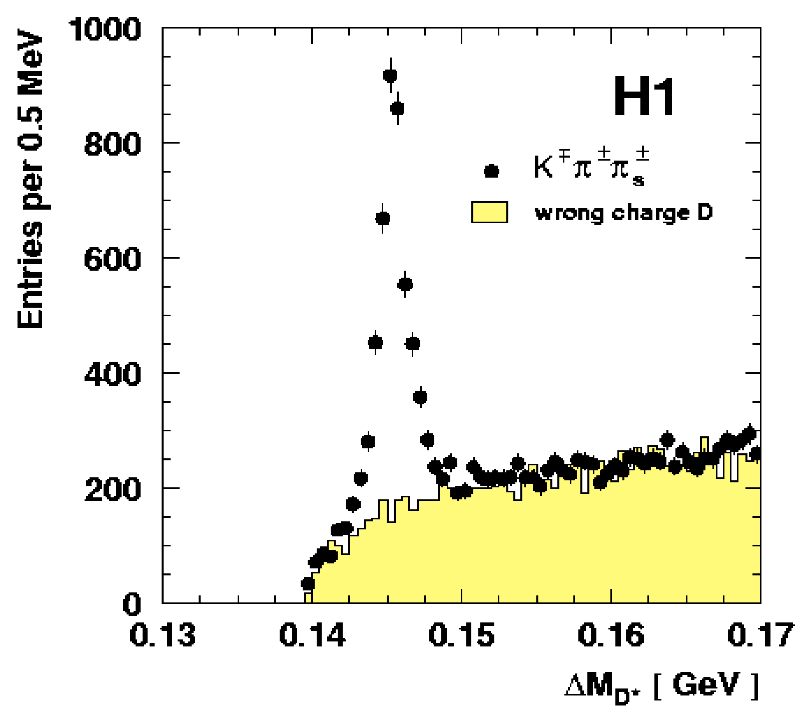
signal from bgr or from D*, protons?

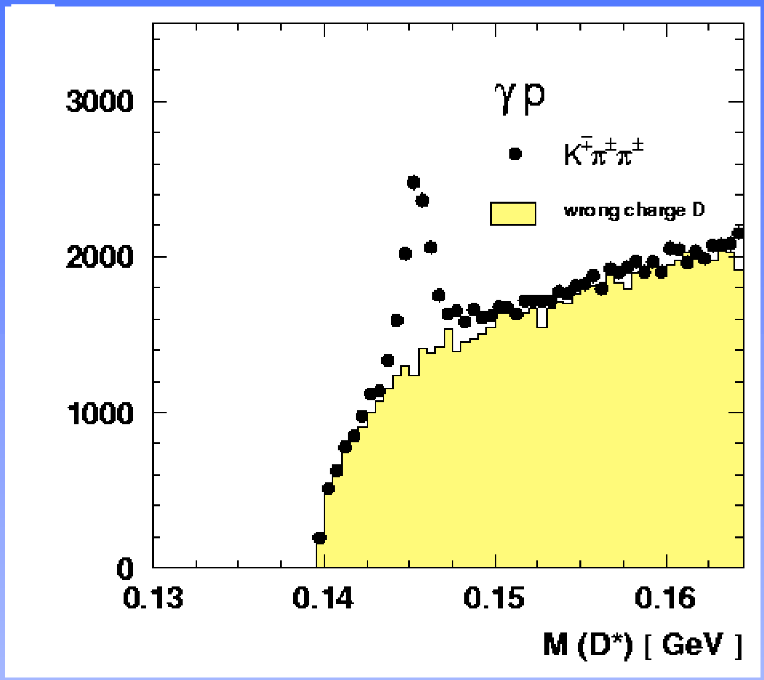
- wrong charge D bgr instead of real D*: no peak
- D* sidebands instead of $\Delta M(D^*)$ signal window: no peak
- K, π selected (via dE/dx) instead of protons (p-mass assigned): no peak
- $K\pi$ combinations with masses above region where charm contributes: no peak

check reflections

- protons assigned K, π mass: no peak
- Invariant masses m(pK), m(pπ), m(pπ_s) and all other possible 2-particle masses: no res. structures
- reflections from D_1^0, D_2^{0*}: expected contribution (MC): 4 events (±24MeV)
- Signal due to $D^{*0} \to D^0 \gamma \to D^0 e^+ e^-$? no (electrons misidentified as πs and proton)

D* signal in DIS and photoproduction

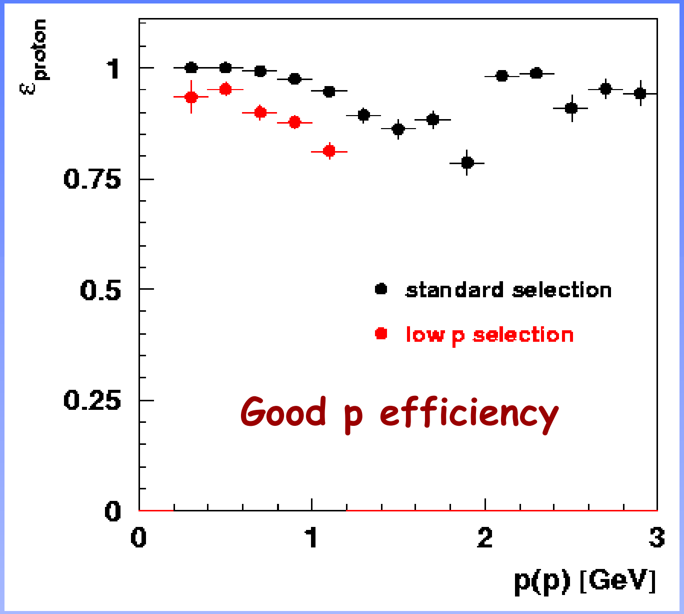




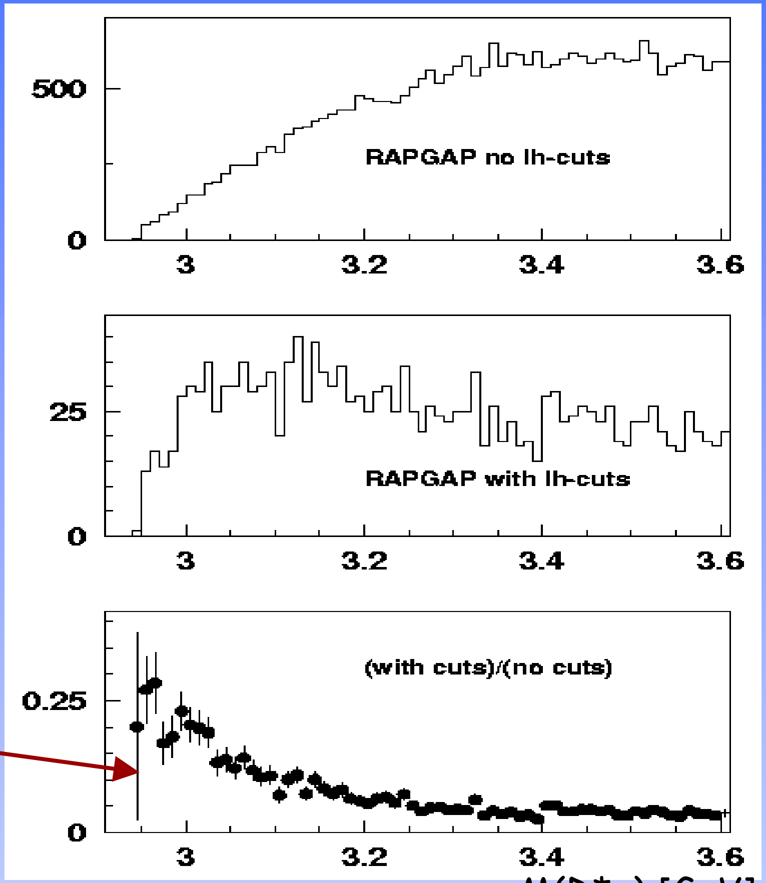
- DIS cleaner signal
- photoproduction: supporting evidence

Acceptance effects?

Proton efficiency



"Pion survival probability"



M(D*p) [GeV]

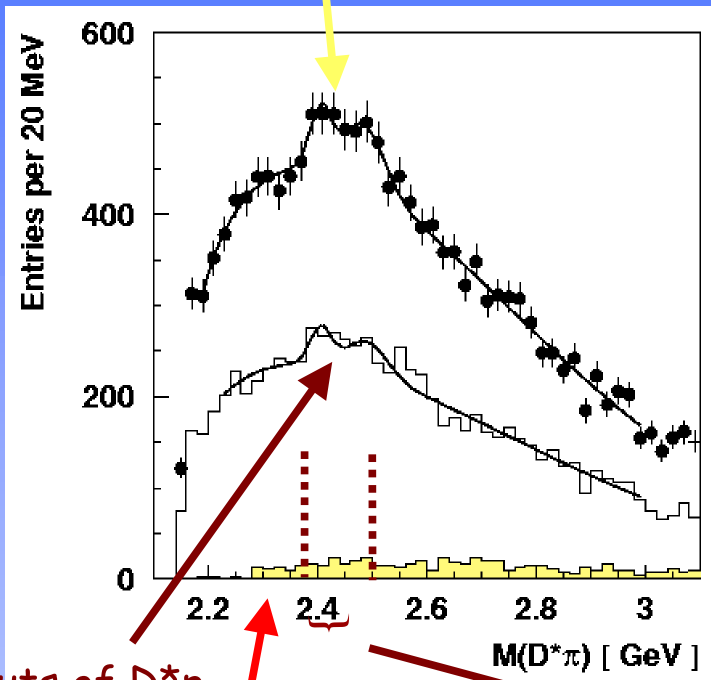
Smooth variation with M(D*p)
Shape reflects opening of
phase space

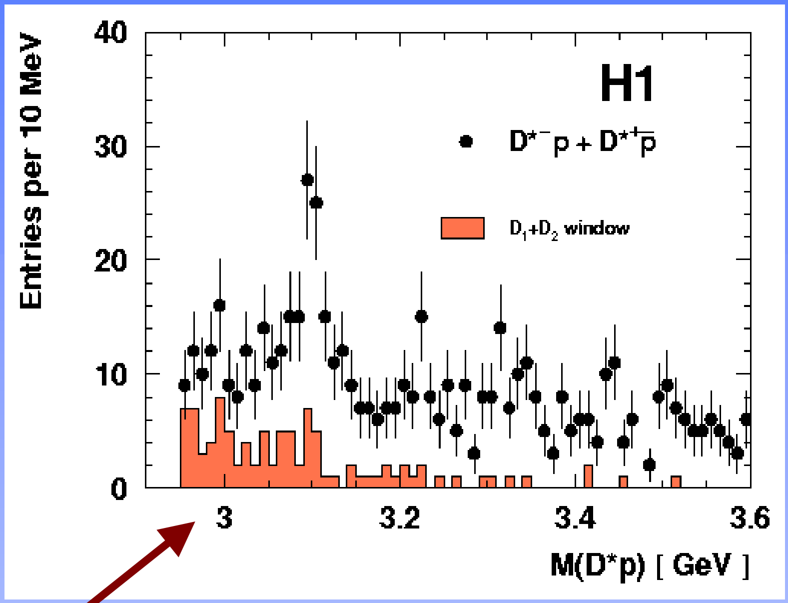
$M(D^*p) = m(K\pi\pi p) - m(K\pi\pi) + M_{PDG}(D^*)$

Reflections from decays to D*π ?

loose D* cuts
π selection

$D_1^0, D_2^{0*} \rightarrow D^*\pi$





D* cuts of D*p
π selection

D_1 , D_2 window

D* cuts of D*p
proton selection

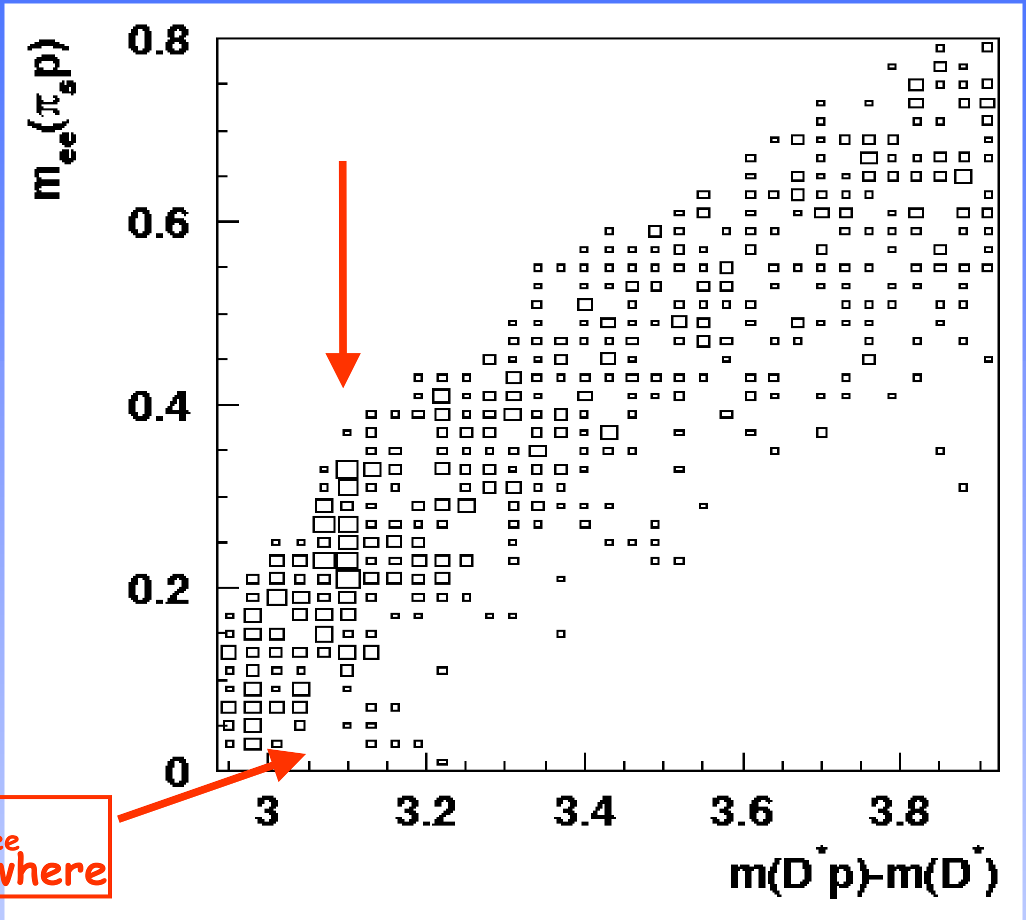
Expect 3.5 decays ($D_1^0, D_2^{0*} \rightarrow D^*\pi$) in D*p signal

Could signal be due to decay $D^{0*} \rightarrow D^0 \gamma$?

$D^{0*} \rightarrow D^0 \gamma \rightarrow D^0 e^+e^-$

electrons from γ-conversion

- asymmetric in energy
- misidentified as proton and π_s ?



No accumulation at small m_{ee}
in D*p signal region or elsewhere

Non observation at ZEUS

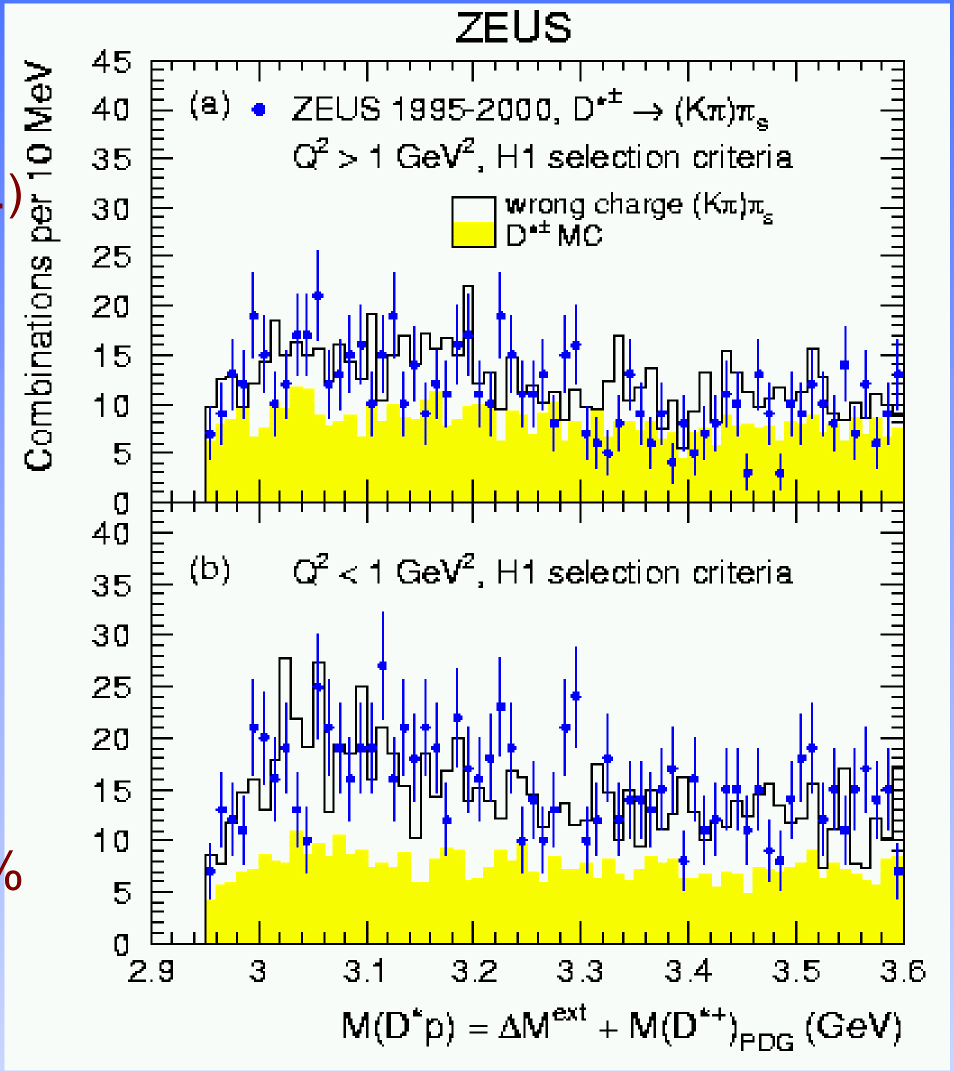
D* decay channels:

$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi_s^+$ (+ c.c.)
$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+\pi^+\pi^- \pi_s^+$ (+ c.c.)
> 60000 D*

DIS (Q^2>1GeV^2) and
photoproduction (Q^2<1GeV^2)
1995-2000 data, 127 pb^{-1}

No peak observed
results not compatible with H1

Upper limit on R($\theta^0_c \rightarrow$ D*p/D*) : 0.35%
(both channles, Q^2>1GeV^2)



Lots of further kinematic test

- **Reflections from a possible signal in D*K mass distribution:** **ruled out**
- **Possible contributions from $D^{*0} \rightarrow D^0 \gamma$ with γ-conversion:** **ruled out**
- **Possible contributions from D_{S1} /$D_{S2} \rightarrow D^0$ K:** **ruled out**
- **Possible peak structures in all possible mass correlations with all possible mass hypotheses of the particles making the D* and the D*p system to search for real or fake resonances, e.g Λ, Δ^0, Δ^{++}, K^0_S, ϕ, f^2**

  no enhancements found
- **Possible peak structures in all possible mass correlations among the proton candidate the remaining charged particles of the event with all possible mass assignments to search for real or fake peaks,**

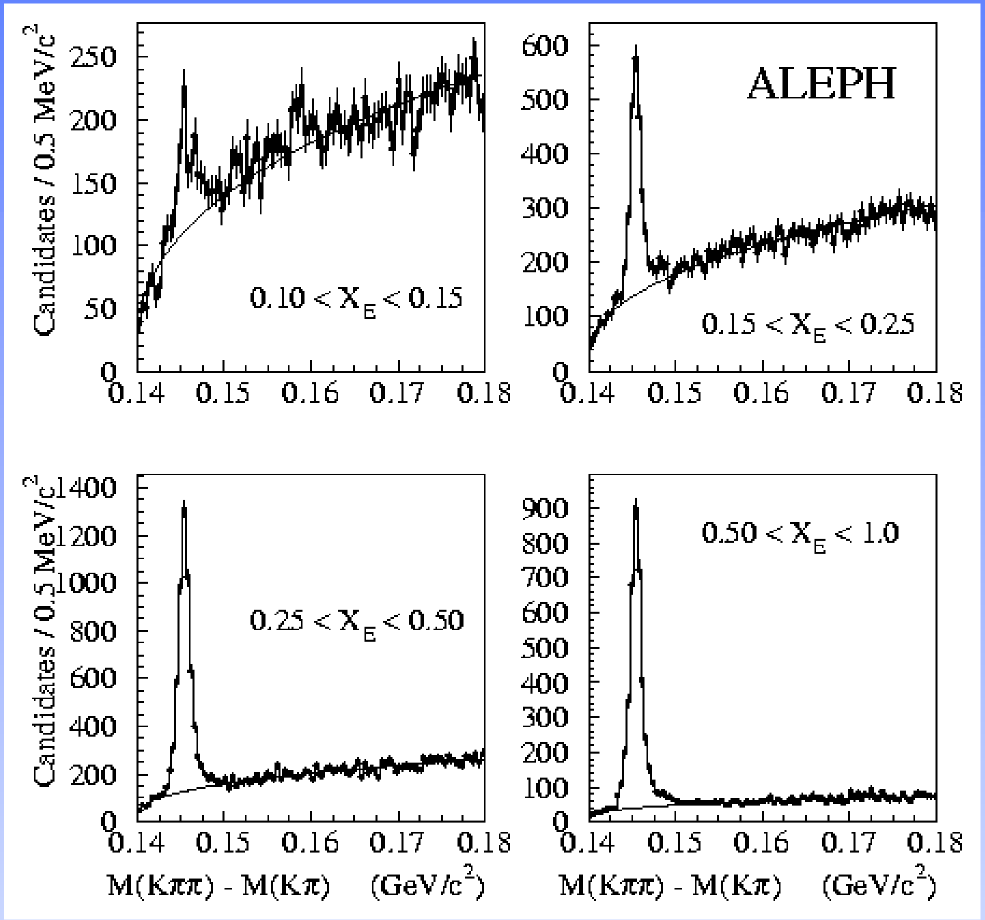
  no enhancements found

Remarks on D*p searches at LEP

$R_b \approx 22\%$, $R_c \approx 17\%$

D* @ LEP are produced predominantly by beauty

D* signals for different x_E



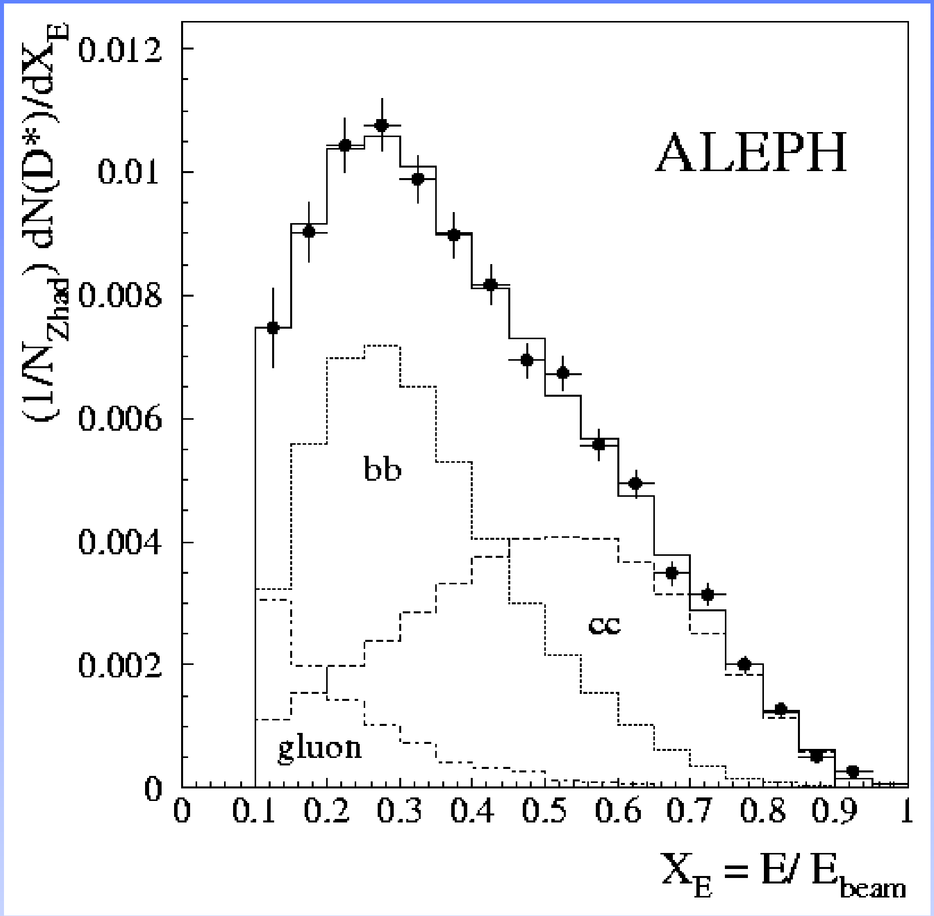
D* acceptance vs. x_E?

Remarks on D*p searches at LEP

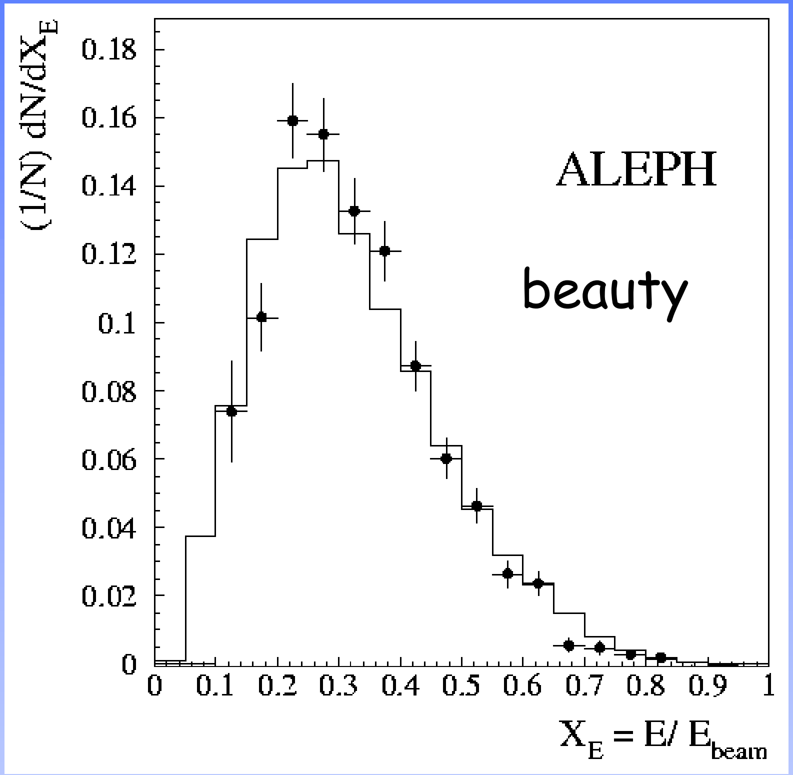
$R_b \approx 22\%$, $R_c \approx 17\%$

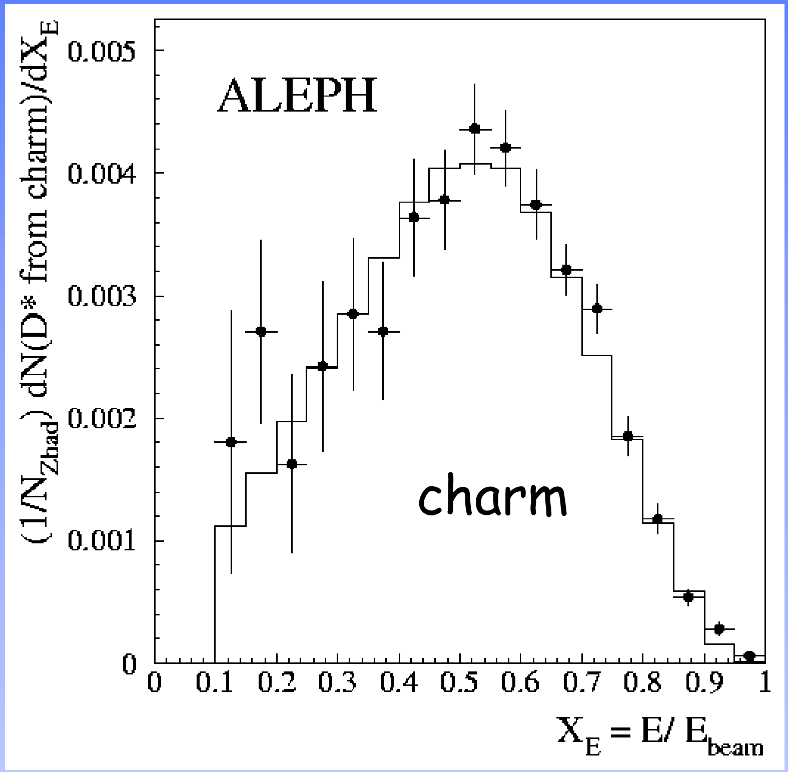
D* @ LEP are produced predominantly by beauty

$\langle x_E \rangle_{cc} \approx 0.488$

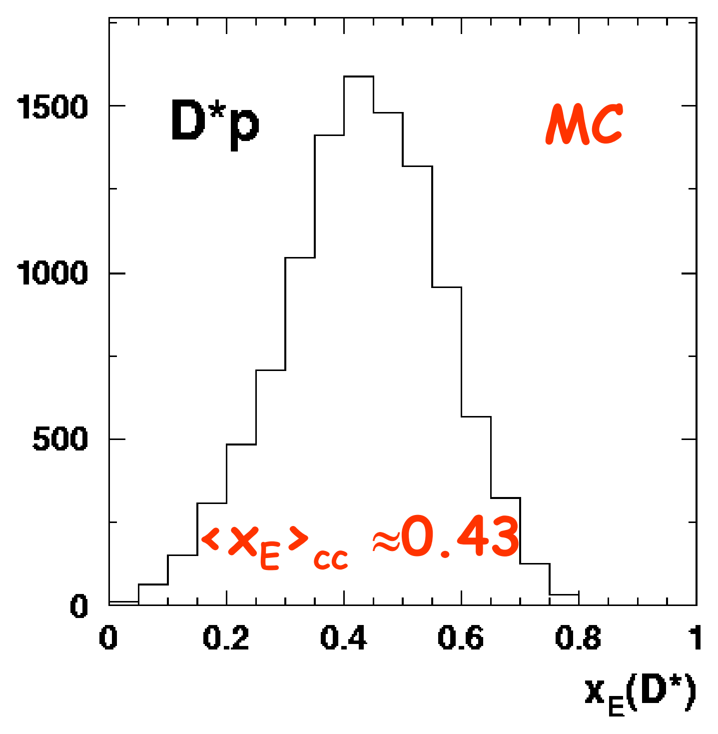


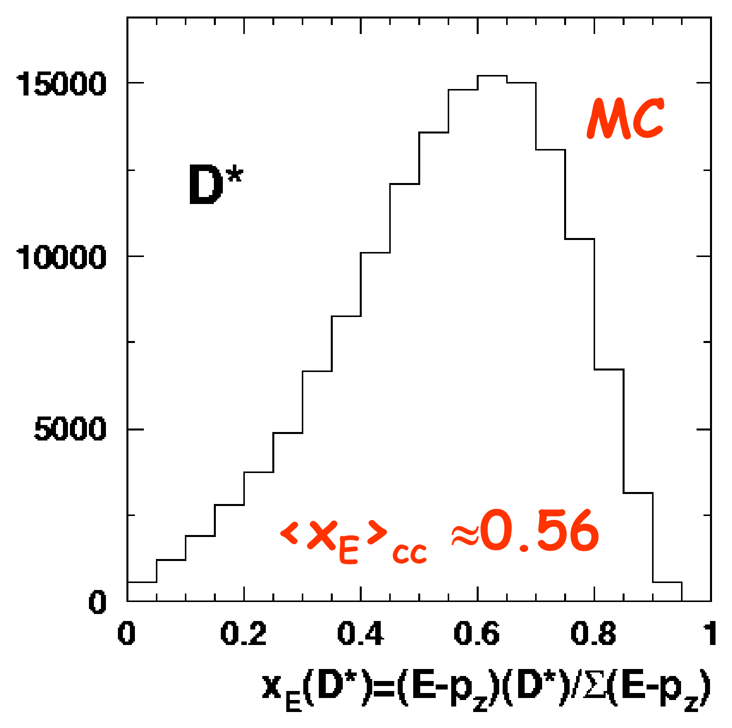
Remarks on D*p searches at LEP





D* from D*p and direct D* at HERA



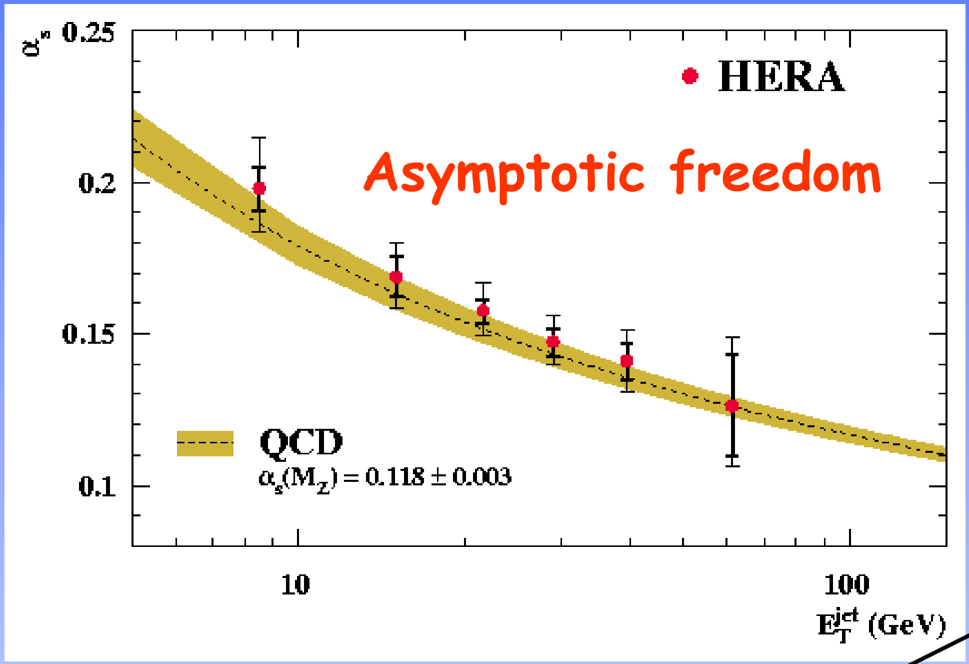


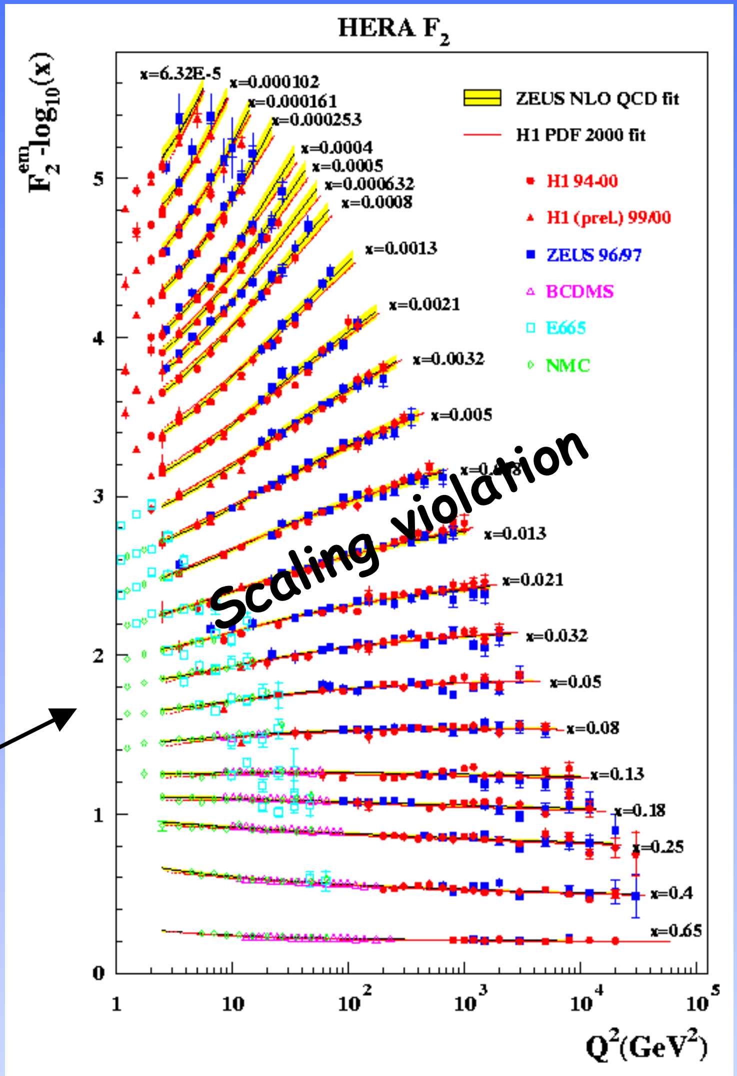
D*'s from D*p significantly softer than normal D*'s

Should also hold for LEP !

Physics at Hera

Strong coupling constant α_s at Hera





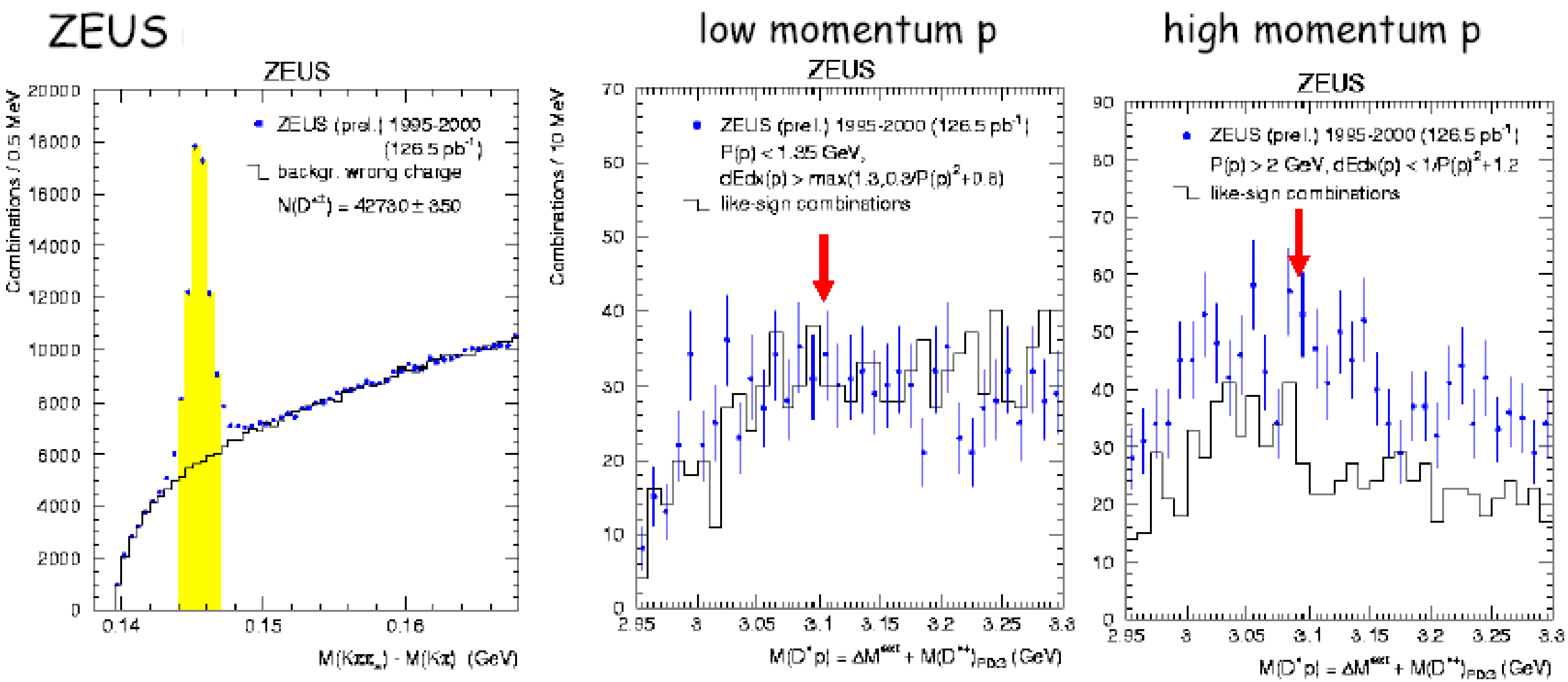
Proton structure function

Different processes give consistent picture of QCD

Search for charmed PQ, $\theta_c \rightarrow D^*p$, in ZEUS

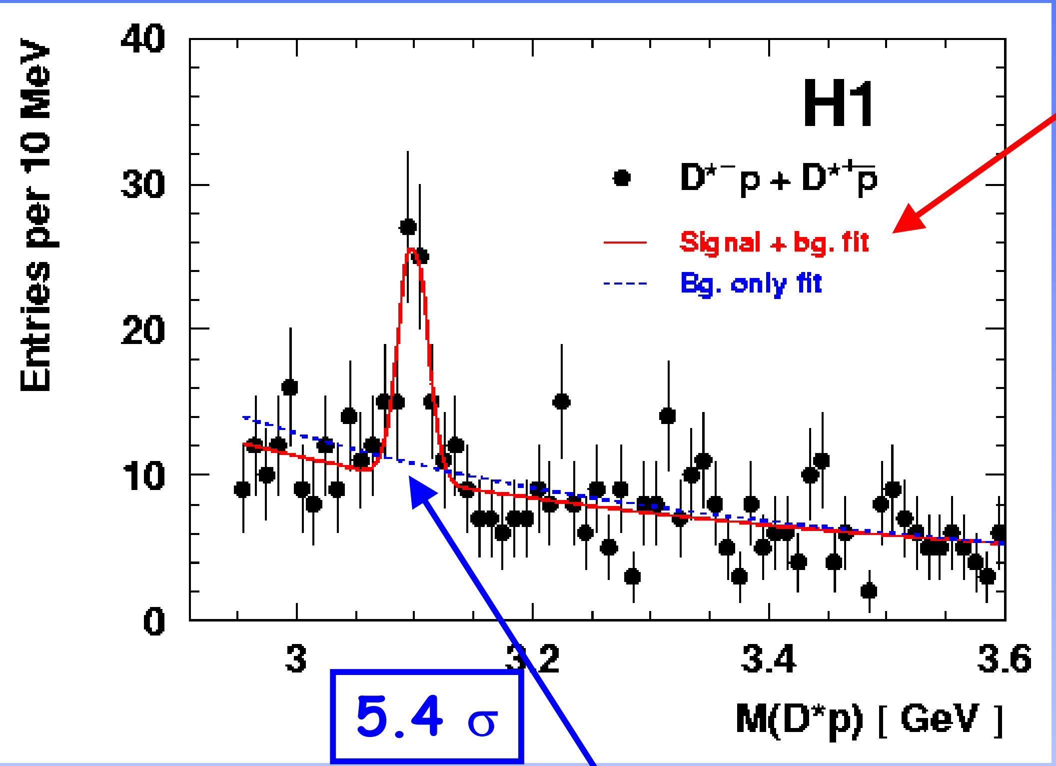
Photoproduction

- ZEUS inclusive D* sample 1995-2000: ~43000 D*
- same D*, p and D*p cuts as for DIS selection



no evidence for a signal at 3.1 GeV

Significance estimate



background + signal hypothesis Fit:

Mass: 3099 ± 3(stat) ± 5(syst) MeV

Width: 12 ±3 MeV

(consistent with experimental resolution)

Numbers of signal and bg. within 2σ

N_b = 45.0 ± 2.8

N_s = 50.6 ± 11.2 (~ 1% of D* yield)

Background only hypothesis: N_b=51.7±2.7

Background fluctuation probability: 4×10^{-8} (Poisson)=5.4 σ (Gauss)