

Pentaquark Searches with ZEUS

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for the ZEUS Collaboration

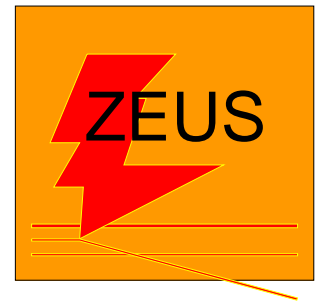
ICHEP - Beijing, August 2004

Introduction

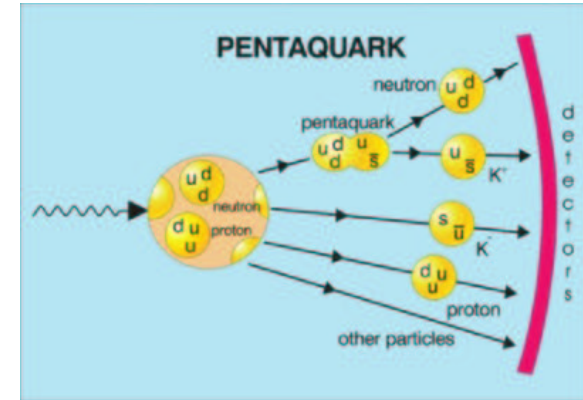
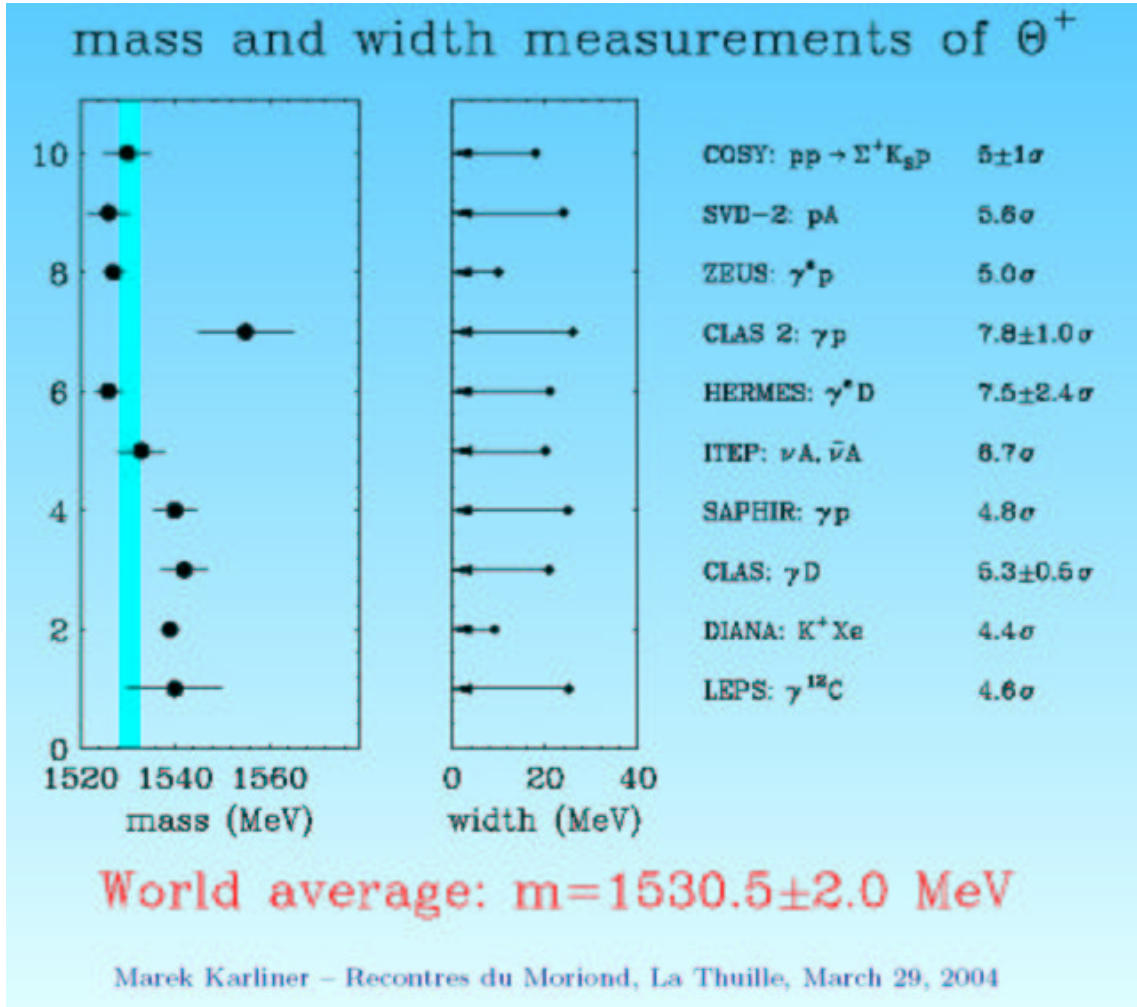
Strange Pentaquarks: Θ^+ , Ξ^{--}

Charm Pentaquark: Θ_c

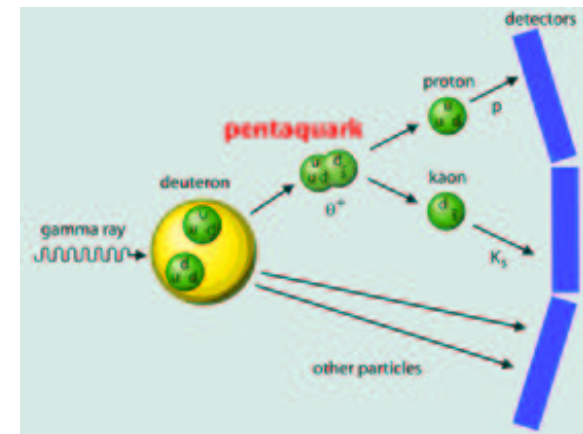
Conclusions



Evidence of Pentaquarks



$\Theta^+ \rightarrow nK^+ \Rightarrow$ higher mass



$\Theta^+ \rightarrow pK_S^0 \Rightarrow$ lower mass

Also evidence for:

NA49: Ξ^{--} (ddss \bar{u})

H1: Θ_c (uudd \bar{c})

Fixed target: pq's use valence quarks

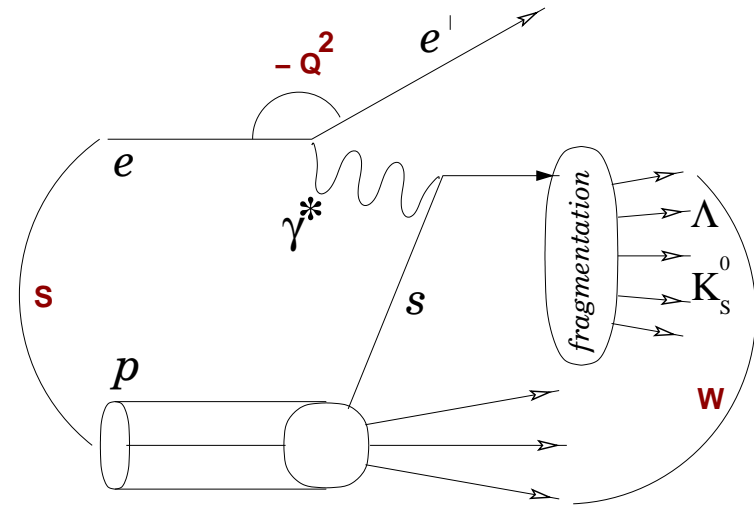
High energy: pq's via fragmentation

Pentaquarks in High Energy Collisions

HERA: $e^\pm p \rightarrow e' X$

$\sqrt{s} = 300$ (318) GeV \Rightarrow

ep CM energy before(after) 98

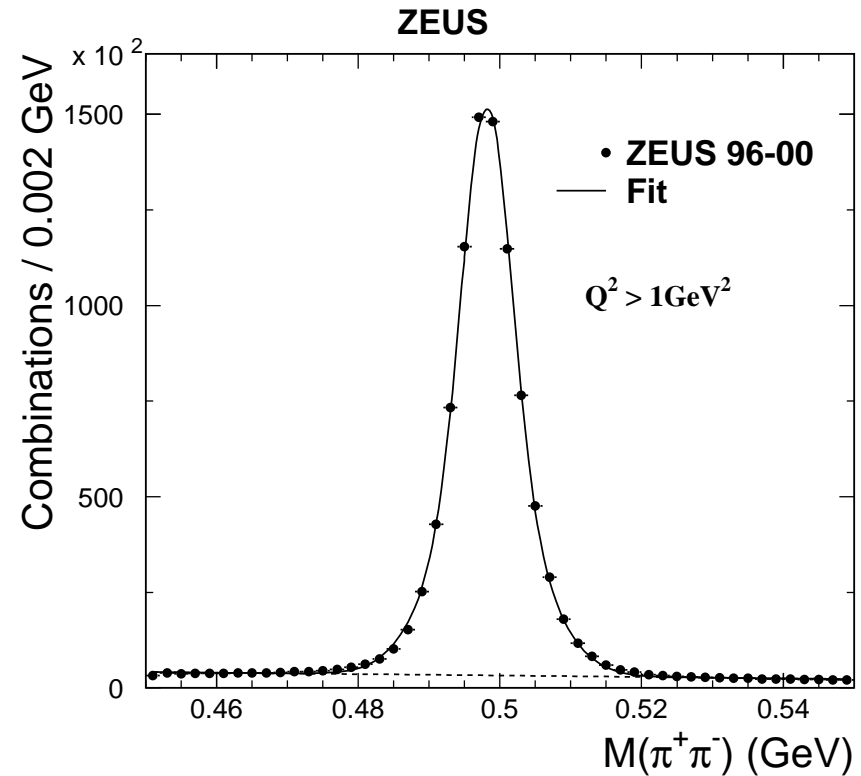
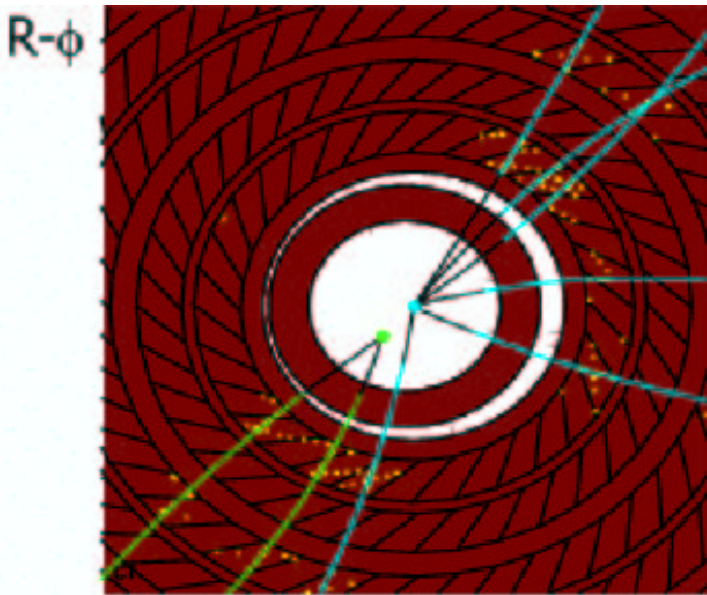


- $Q^2 = -q^2$: photon virtuality
 $Q^2 > 1 \text{ GeV}^2$: DIS
(require scattered electron)
 $Q^2 < 1 \text{ GeV}^2$: γ -production
- $W = m(\gamma^* p)$: $\gamma^* p$ energy

NB: $\bar{u}\bar{u}\bar{d}\bar{d}s$ ($\bar{\Theta}^-$) can only be produced in fragmentation!

Search for Strange Pentaquark: K_S^0 Selection

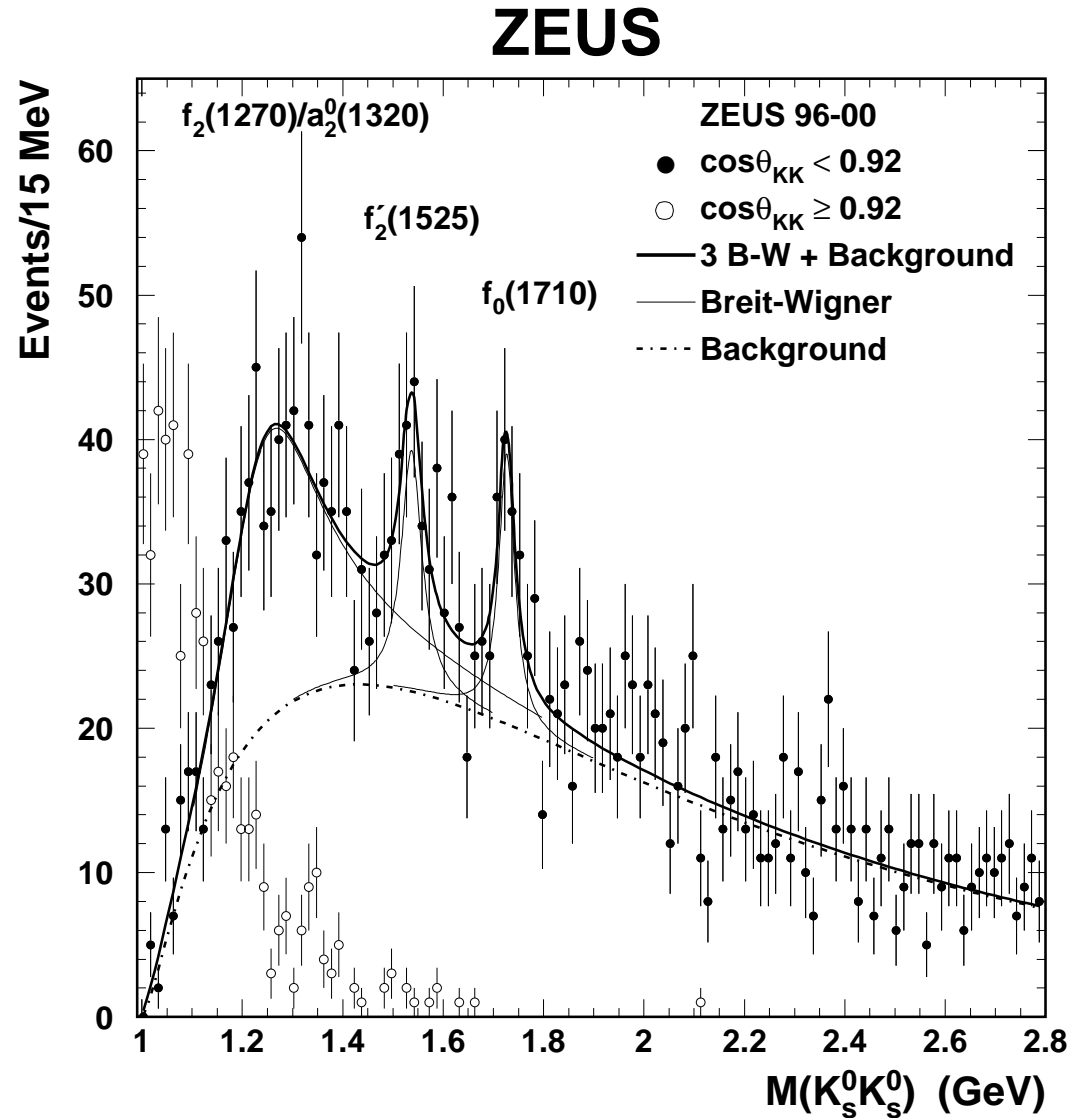
- $\Theta^+ \rightarrow K_S^0 p$ ($\bar{\Theta}^- \rightarrow K_S^0 \bar{p}$)
reconstruct $K_S^0 p(\bar{p})$ inv mass
- Inclusive DIS event sample:
96 – 00 data \Rightarrow 121 pb^{-1}
- K_S^0 Selection
 $p_T(K_S^0) > 0.3$, $|\eta(K_S^0)| \leq 1.5$
remove Λ and γ conversions



- Peak: $498.12 \pm 0.01 \text{ MeV}$
- Background: $< 6\%$
- Candidates: $\sim 870,000$
- Resolution: $2 \pm .5 \text{ MeV}$ (MC + consistent w/ K^* measurement)

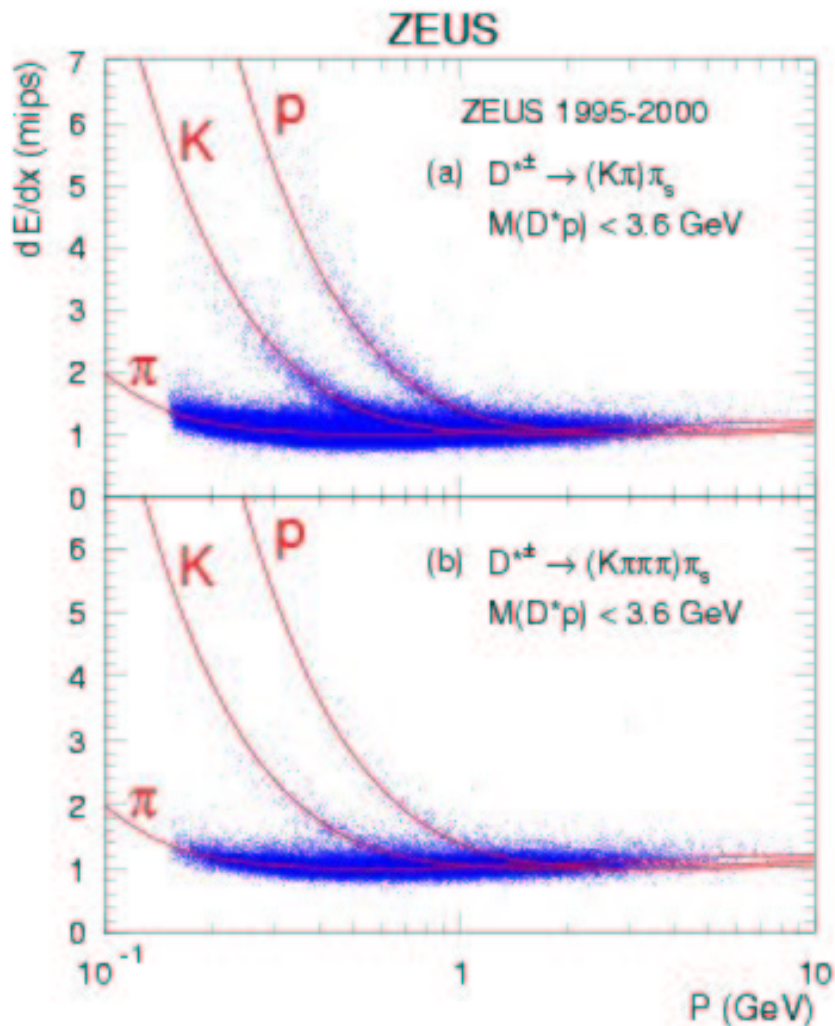
Intermezzo: $K_S^0 K_S^0$ resonances (Phys. Lett. B 578)

- Several resonances observed
- $f_0(1710)$: glueball?
- Produced in gluon rich environment



Proton Identification

(anti)proton selection \implies define ionization band in dE/dx



- expectations tuned using tagged protons and pions from Λ and K_S^0 decays
- Strange pentaquark
 $dE/dx > 1.15$ mips
 $P(p) < 1.5$ GeV
 $\sim 60\%$ proton purity
- Charmed pentaquark
 $l_p > 0.15 \implies$
 $A(l_p > 0.15) = 85.0 \pm 0.1\%$

dE/dx Check: $\Lambda^0(1520)D_{03} \longrightarrow pK^- + \text{c.c.}$

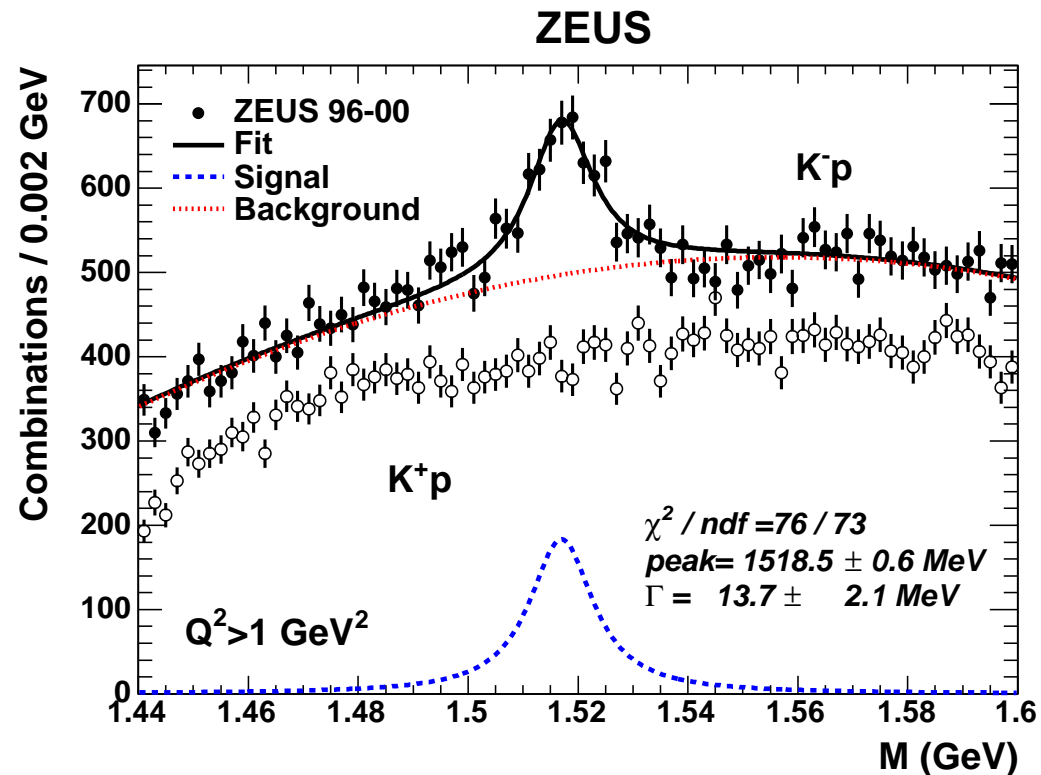
Select p, K using dE/dx \Rightarrow

Well established narrow d-wave uds state \Rightarrow isospin 0, charge 0

Isospin 1 partner expected to have higher mass

$\Rightarrow \Sigma^+, X^{++}$ not expected in same place

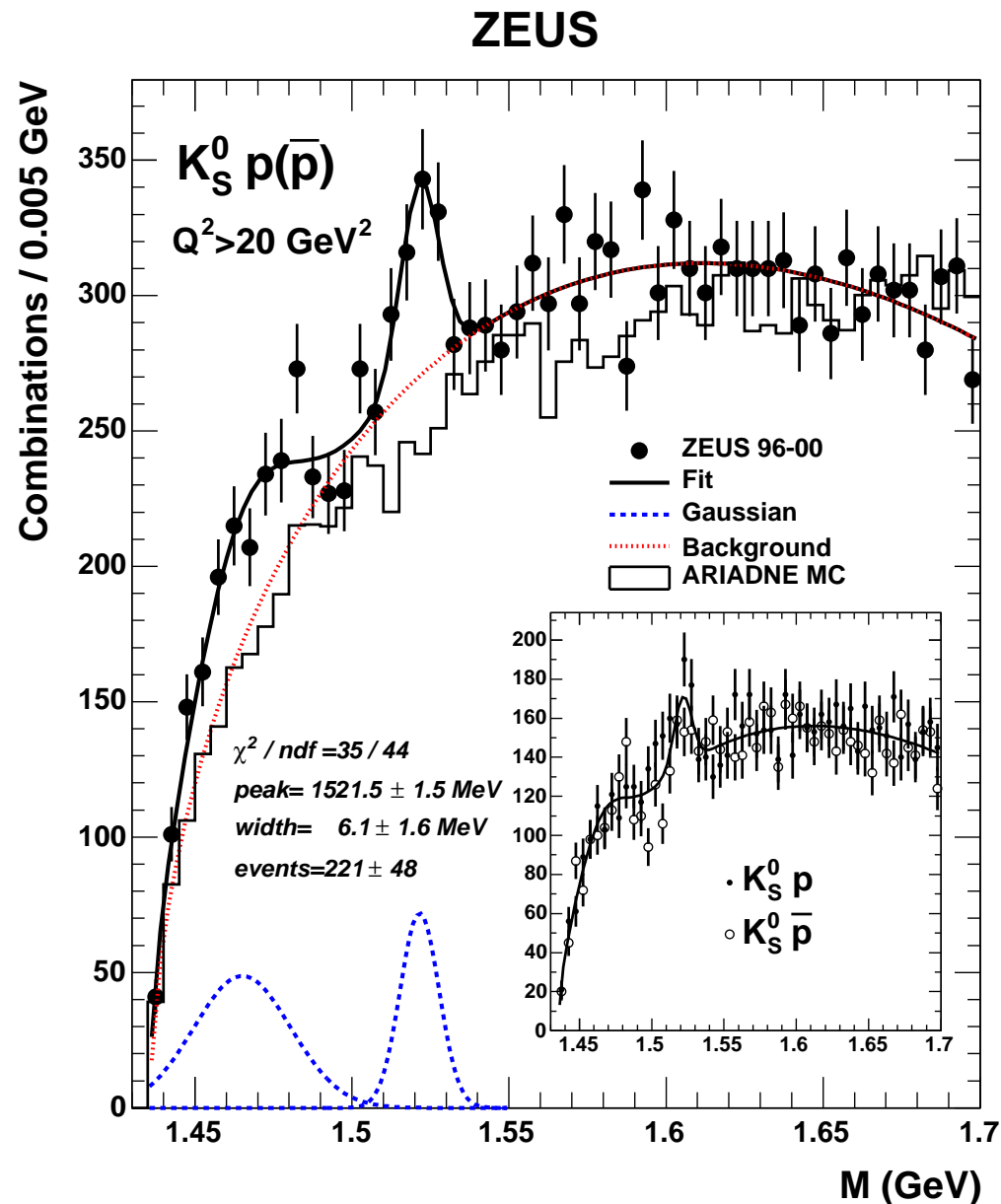
- resonance in $pK^- + \text{c.c.}$
- no resonance in $pK^+ + \text{c.c.}$
- mass and natural width consistent with PDG:
 $M = 1519.5 \pm 1.0 \text{ MeV}$
 $\Gamma = 15.6 \pm 1.0 \text{ MeV}$
- no evidence for hypothetical $\Theta^{++}(1530)$ ($I=1$ pentaquark)



Search for Strange Pentaquark: (Phys. Lett. B 591)

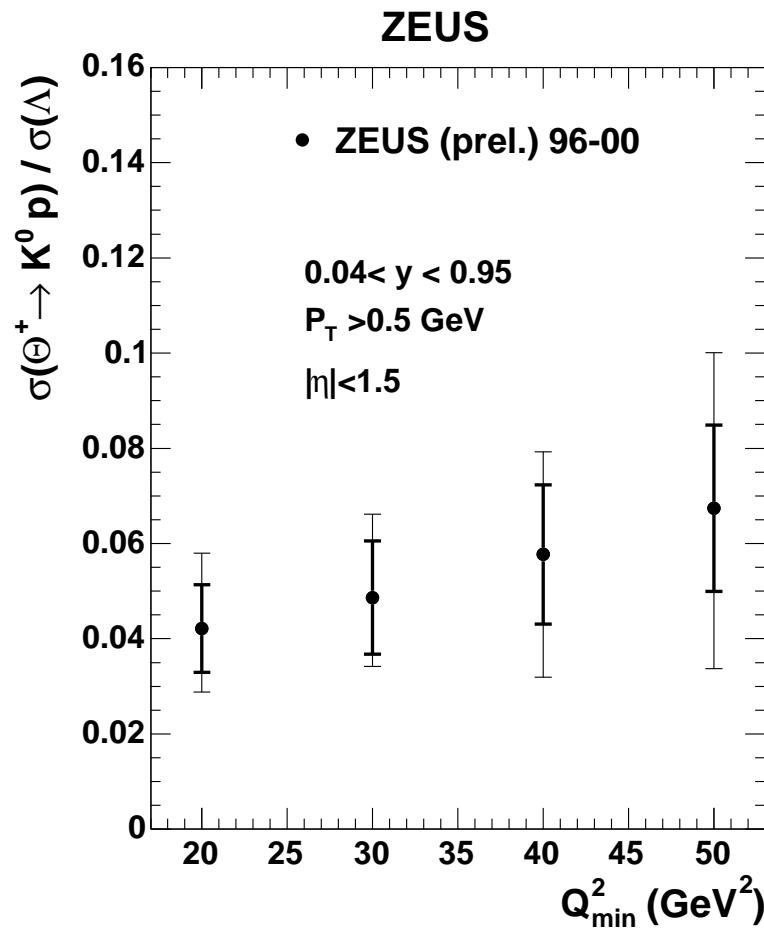
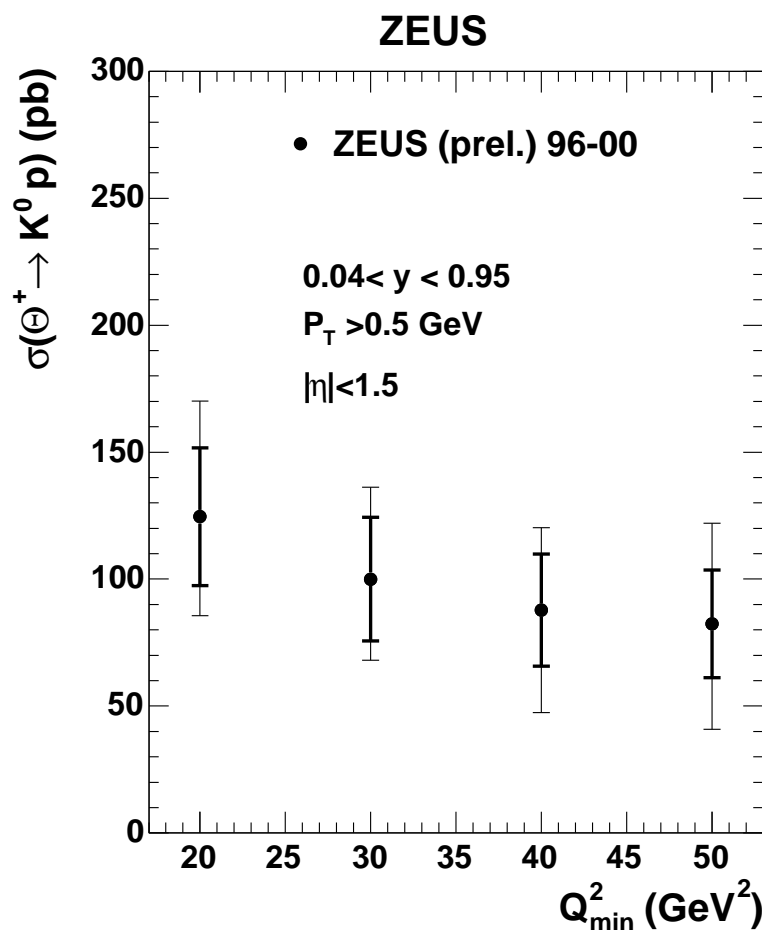
Θ^+ Signal $\Rightarrow p_T(\Theta^+) > 0.5 \text{ GeV}$, $|\eta(\Theta^+)| < 1.5$, $Q^2 > 20 \text{ GeV}^2$

- $M : 1521.5 \pm 1.5(\text{stat})_{-1.7}^{+2.8}(\text{syst})$
- Gaussian W: $6.1 \pm 1.5 \text{ MeV}$
BW Fit: $\Gamma = 8 \pm 4 \text{ MeV}$
 \Rightarrow compatible w/ experimental resolution $\sim 2 \text{ MeV}$
- Fit: 3P Background + 2 Gaussians $\Rightarrow \sim 4.6 \sigma$
- $\chi^2/\text{ndf} = 35/44$
- single Gaussian fit \Rightarrow worse χ^2/ndf , peak robust
- if $K_S^0 p$ interpreted as Θ^+ then $K_S^0 \bar{p} \Rightarrow \bar{\Theta}^-$ (antipentaquark)?



Θ^+ Cross sections and ratios ($\Theta^+ \rightarrow K^0 p$ / $\Lambda \rightarrow p\pi$)

$$Q^2 > 20 \text{ GeV}^2, \quad P_T > 0.5 \text{ GeV}, \quad |\eta| < 1.5$$

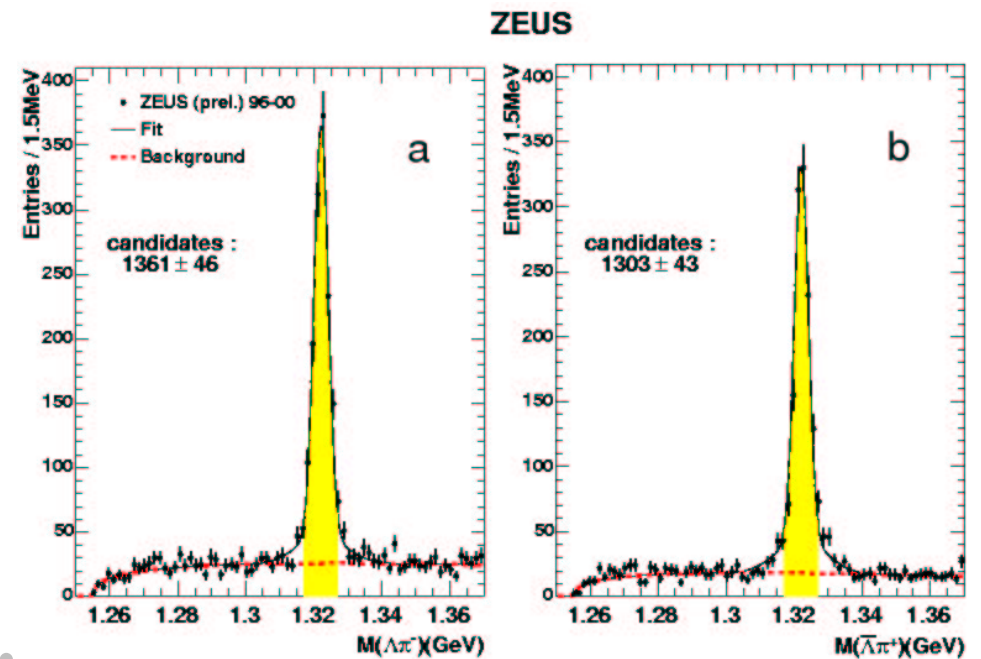
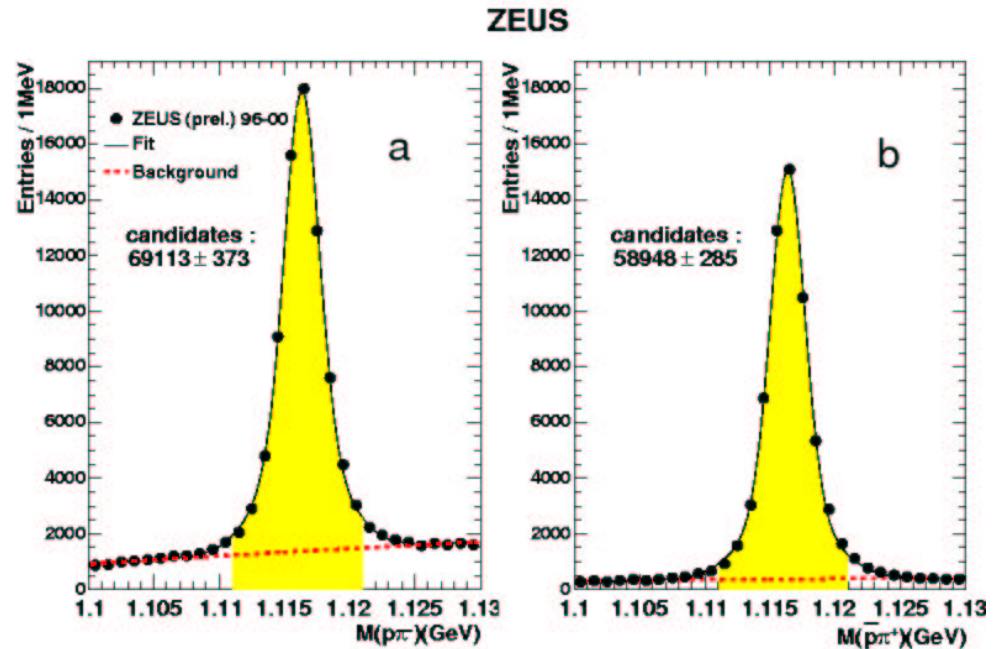
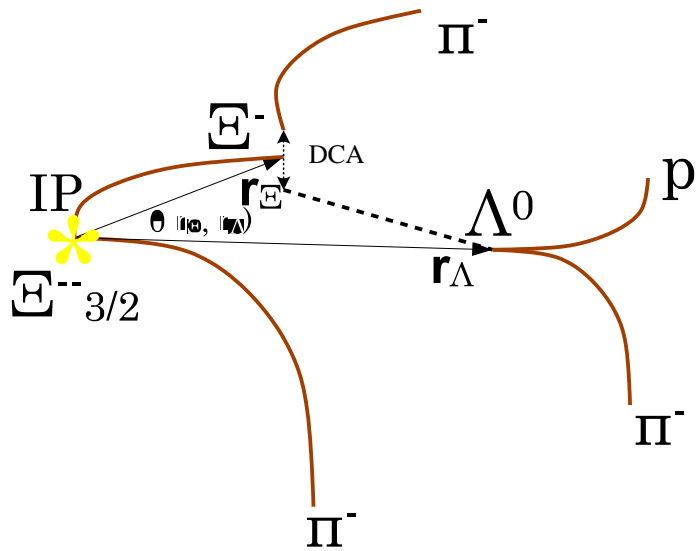


- $\sigma(ep \rightarrow e\Theta^+ X)$: $125 \pm 27(\text{st})_{-40}^{+45}(\text{sy})$ pb
- $N(\Theta^+ \rightarrow K^0 p(\bar{p})) / N(\Lambda(p\pi))$ as function of Q_{\min}^2 :
 $4.2 \pm 0.9(\text{st})_{-0.9}^{+1.2}(\text{sy})\%$ \Rightarrow production rate consistent w/ a constant

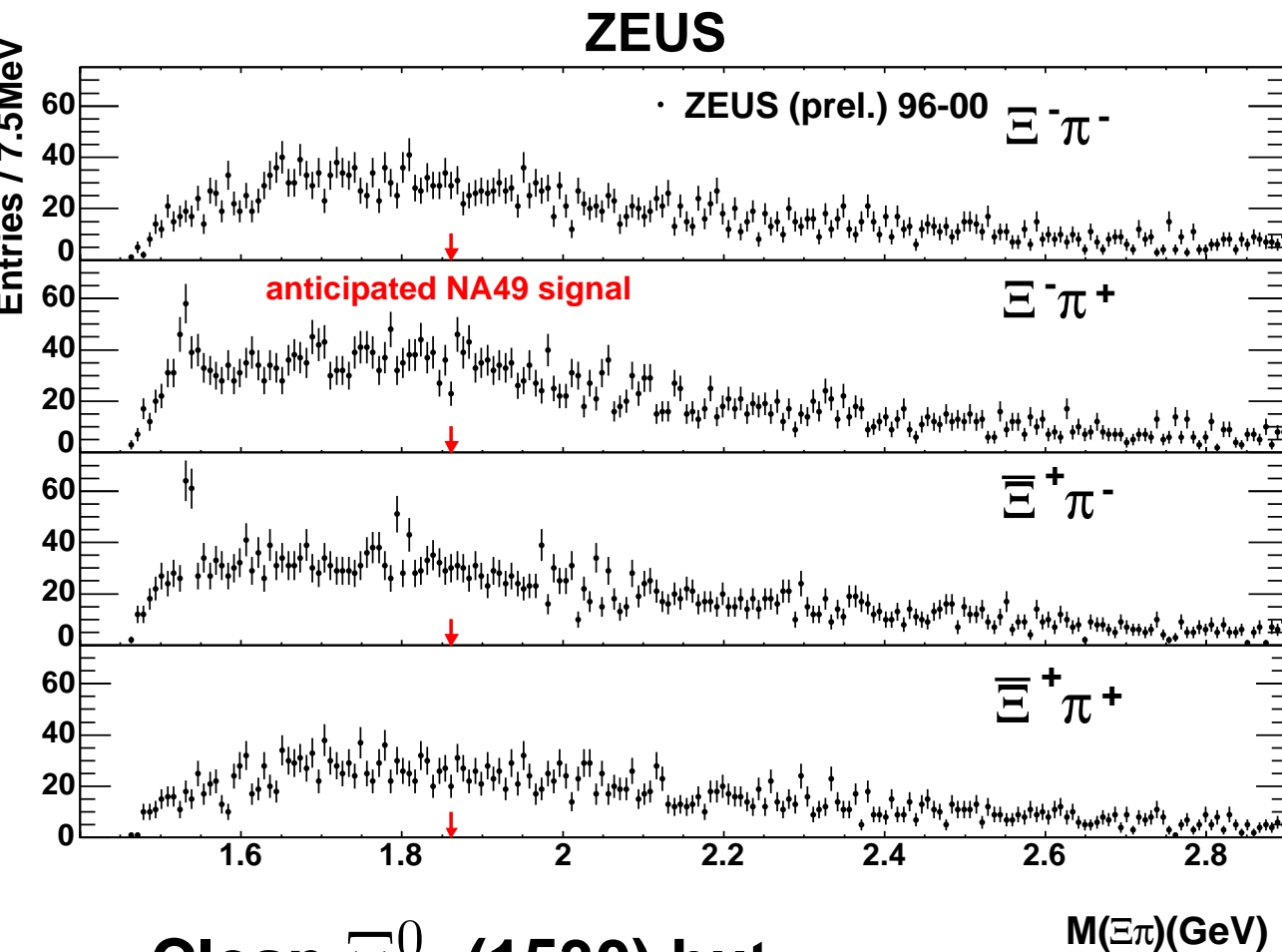
Search for NA49 signal with ZEUS: I

NA49 analysis repeated

- $\Xi^{--} \rightarrow \Xi^- \pi^- \rightarrow \Lambda^0 \pi^- \pi^- \rightarrow p \pi^- \pi^- \pi^-$
- Inclusive DIS event sample:
96 – 00 data $\Rightarrow 105 \text{ pb}^{-1}$
- high stats, small bground



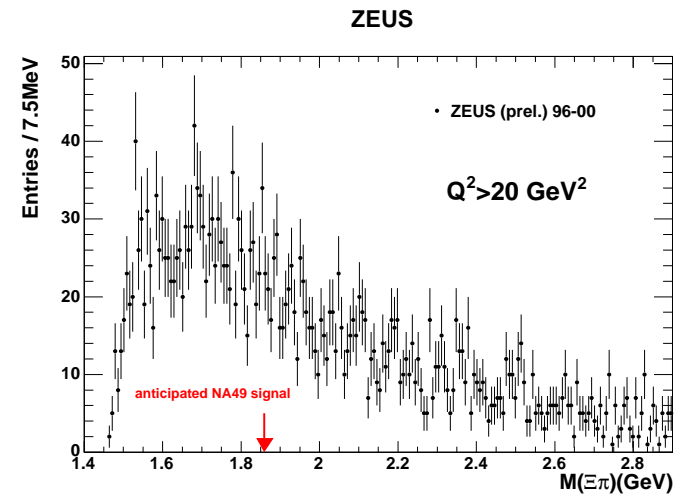
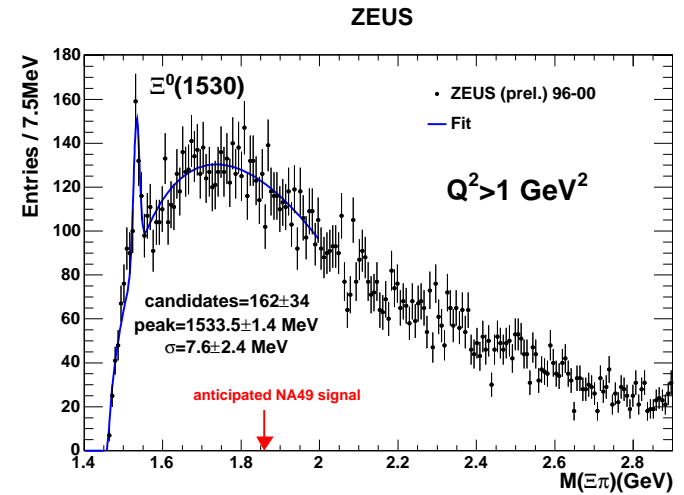
Search for NA49 signal with ZEUS: II



Clean $\Xi_{3/2}^0(1530)$ but...

NO pentaquark signal

(produced in forward region?)



Four channels
combined

Search for Charmed Pentaquark: D^* Selection

- $(\Theta_c \rightarrow D^* p)$
- 95 - 00 data $\Rightarrow 126 \text{ pb}^{-1}$

- D^{*+} Selection:

$$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow$$

$$\underline{1. (K^- \pi^+) \pi_s^+ + (\text{c.c.})}$$

$$p_T(D^*) > 1.35 \text{ GeV}$$

$$\underline{2. (K^- \pi^+ \pi^+ \pi^-) \pi_s^+ + (\text{c.c.})}$$

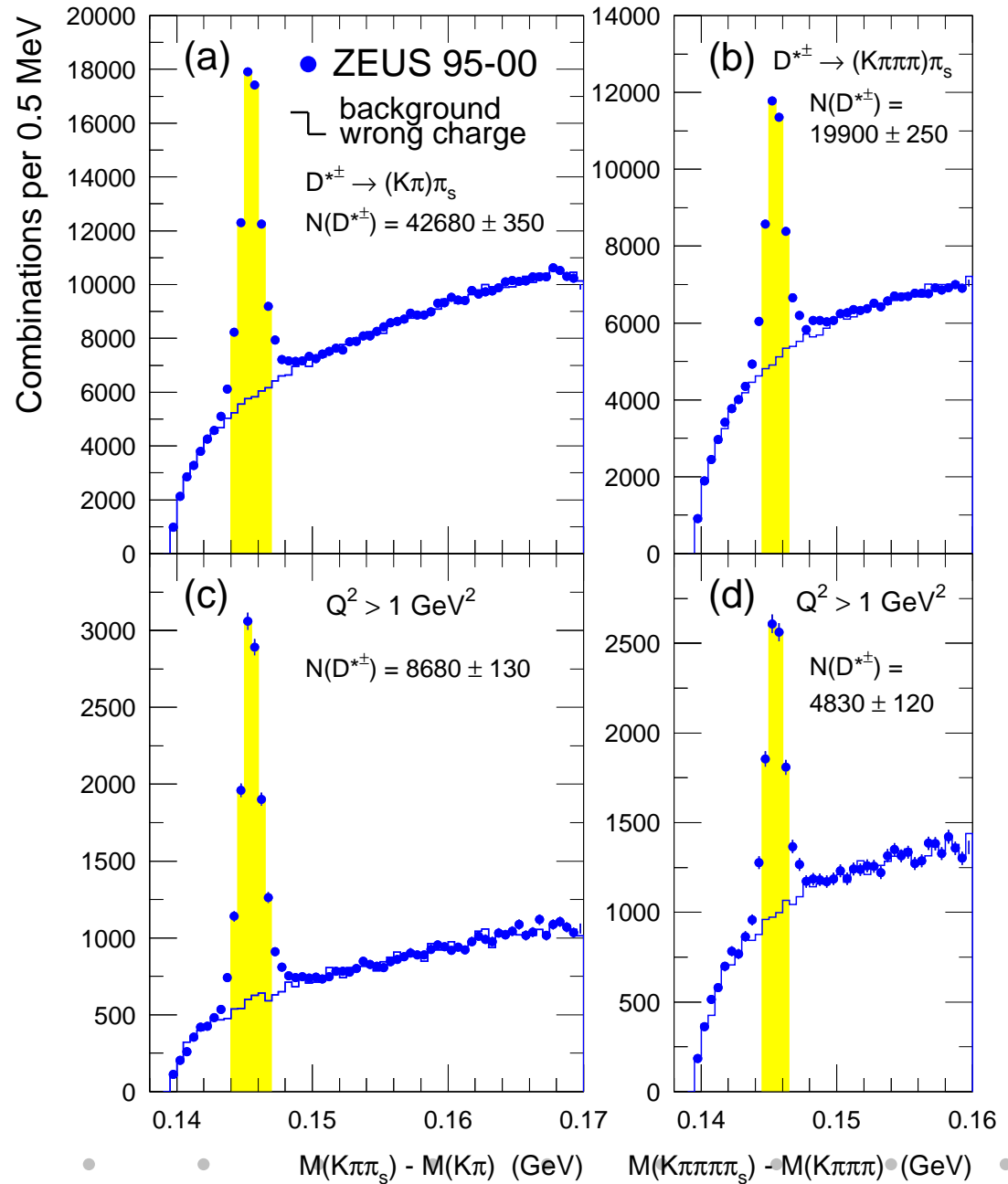
$$p_T(D^*) > 2.8 \text{ GeV}$$

- Number of D^* 's:

Total Sample: $> 62,000$

DIS Sample: $> 13,000$

ZEUS



Search for Charmed Pentaquark: Upper Limits

No signal!

- no signal: either channel
- no signal: $Q^2 > 1 \text{ GeV}^2$
- upper limit at 95 % CL

$$R = N(\Theta_c \rightarrow D^* p) / N(D^* p)$$

$$R < 0.23 \%$$

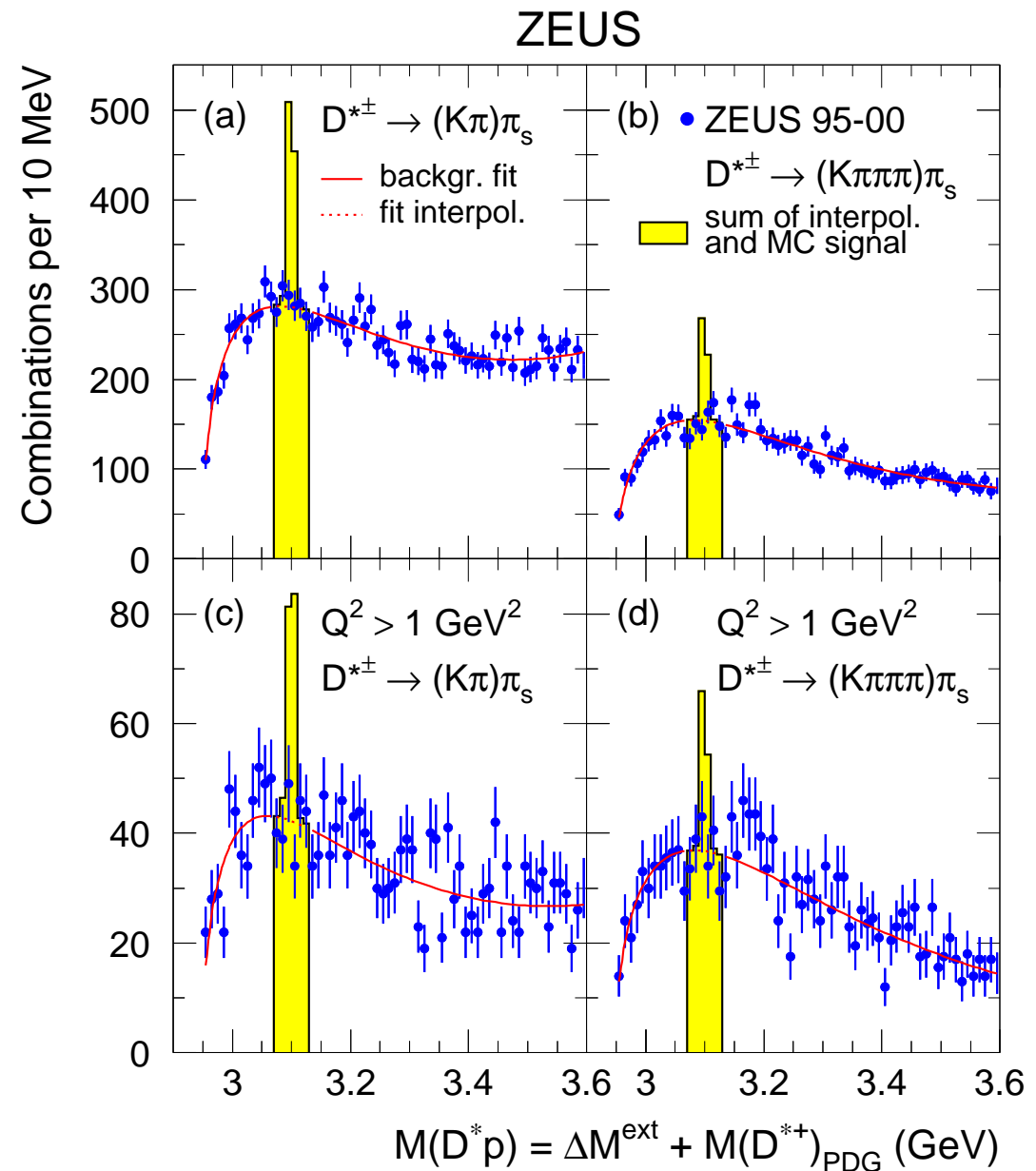
$$R < 0.35 \% \text{ for } Q^2 > 1 \text{ GeV}^2$$

$$R < 0.29 \% \text{ for } Q^2 < 1 \text{ GeV}^2$$

- universal upper limit

$$f(c \rightarrow \Theta_c) \cdot B_{\Theta_c \rightarrow D^* p} < 0.21 \%$$

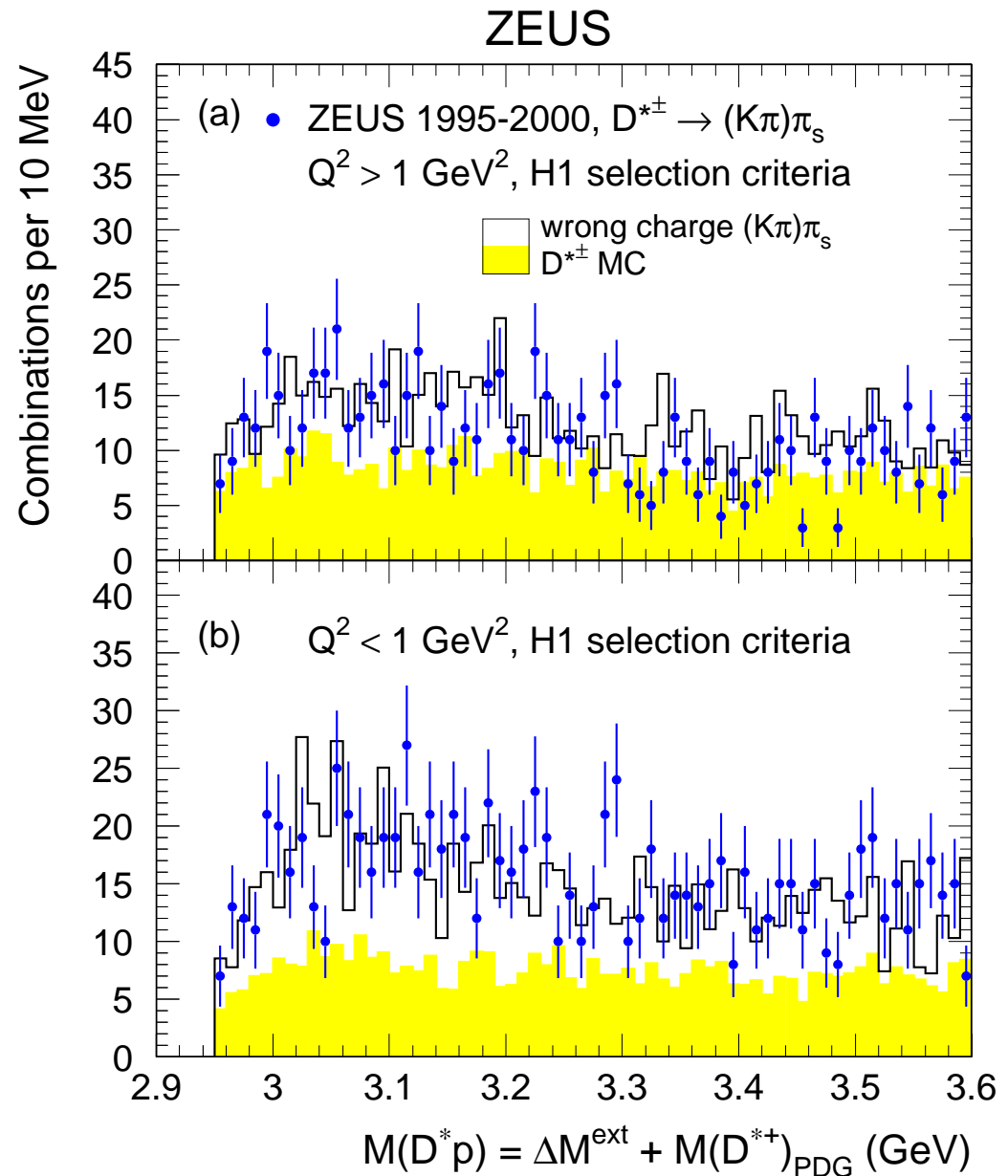
- $R \sim 1 \%$ excluded at 9σ



Search for Charmed Pentaquark: H1 Criteria

H1 Selection ...

- $P_T(D^*)$, $\eta(D^*)$, Q^2 , y
- Tracking cuts
- $Z(D^*) > 0.2$
(vs. ZEUS $P_T/E_T > 0.12$)
- $M(K\pi)$, ΔM :
ZEUS nominal \Rightarrow
(better mass resolution)
Repeated with H1 values
- Number of D^* 's
 $Q^2 > 1 \text{ GeV}^2$: 5920 ± 90
 $Q^2 < 1 \text{ GeV}^2$: 11670 ± 140



In Summary ...

$\Theta^+(1522) \Rightarrow$ peak seen in $M(K_S^0 p)$ and $M(K_S^0 \bar{p})$

- For $Q^2 > 20 \text{ GeV}^2$:

$$M : 1521.5 \pm 1.5(\text{stat})_{-1.7}^{+2.8}(\text{syst})$$

natural width compatible with detector resolution

\Rightarrow consistent with strange pentaquark

- $\Theta^+(\rightarrow K_S^0 p) / \Lambda(\rightarrow p\pi) \Rightarrow \sim 4\%$

production rate consistent with a constant ...

- $K_S^0 \bar{p}$: first evidence of antipentaquark? \Rightarrow fragmentation

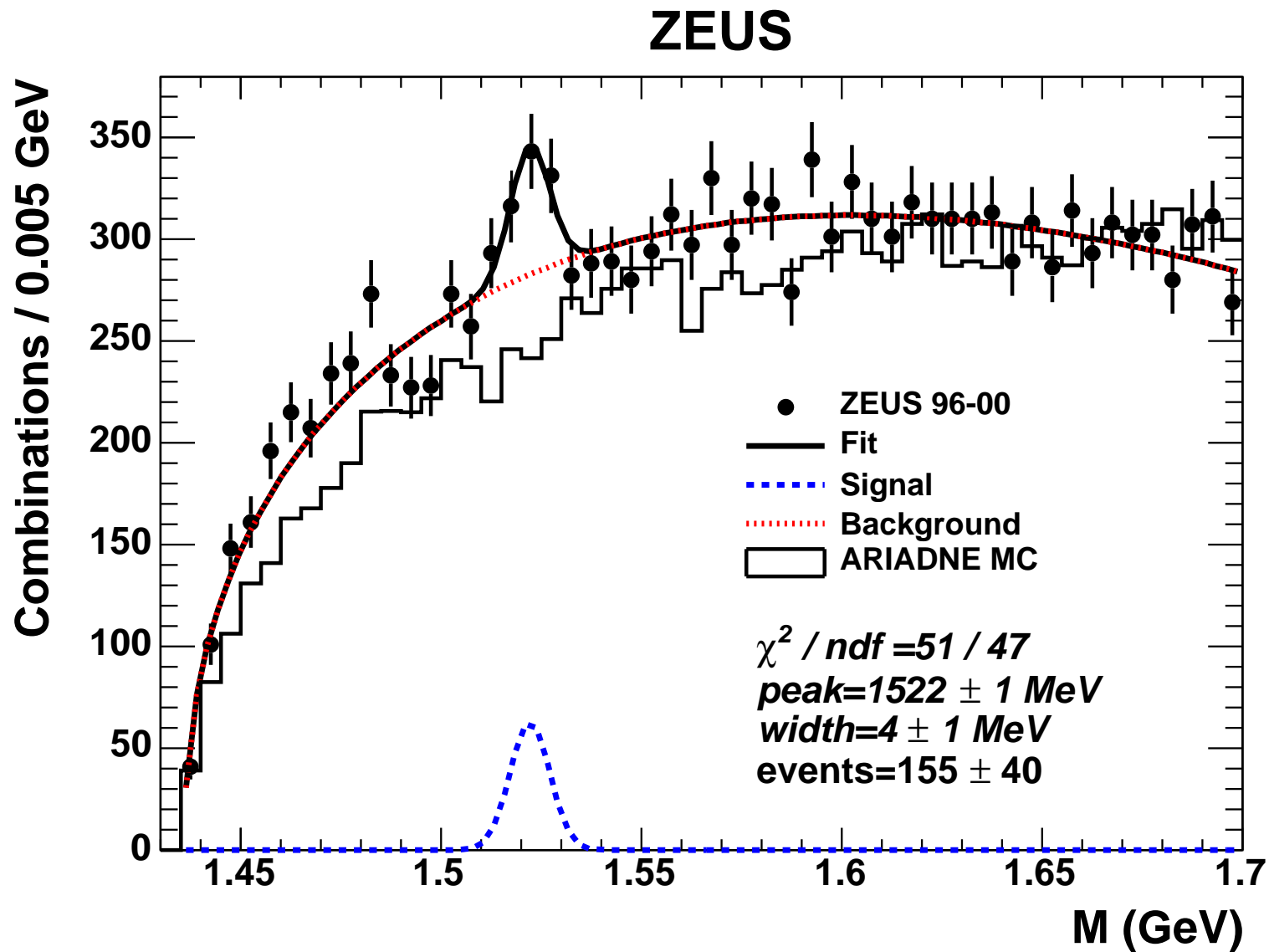
$\Xi^{--}(1860) \Rightarrow$ No Signal

- not confirmed by ZEUS

$\Theta_c(3099) \Rightarrow$ No Signal

- more than 62,000 reconstructed D^* 's
- ZEUS data are **incompatible** with H1 report of Θ_c contributing 1% of D^* production ratio

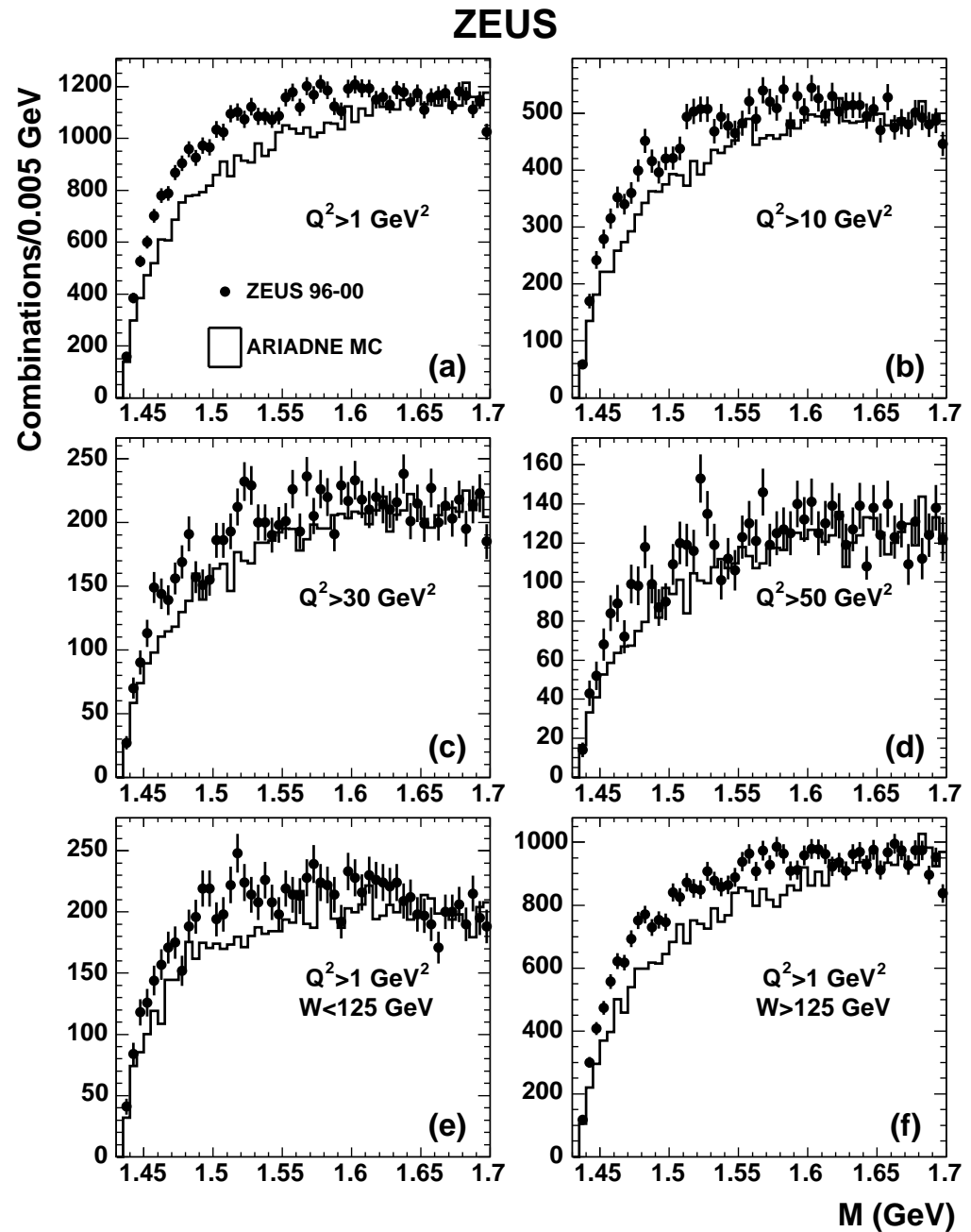
Backup - Θ^+ : Single Gaussian Fit



Backup - Θ^+ : Fit Results

Fit		Gaussian+Bkg.	2 Gaussians + Bkg.
χ^2/ndf	$M \leq 1700$ MeV	51/47	35/44
Peak 1	mass (MeV)	-	1465.1 ± 2.9
	width (MeV)	-	15.5 ± 3.4
	events	-	368 ± 121
Peak 2	mass (MeV)	1522.2 ± 1.5	1521.5 ± 1.5
	width (MeV)	4.9 ± 1.3	6.1 ± 1.6
	events	155 ± 40	221 ± 48

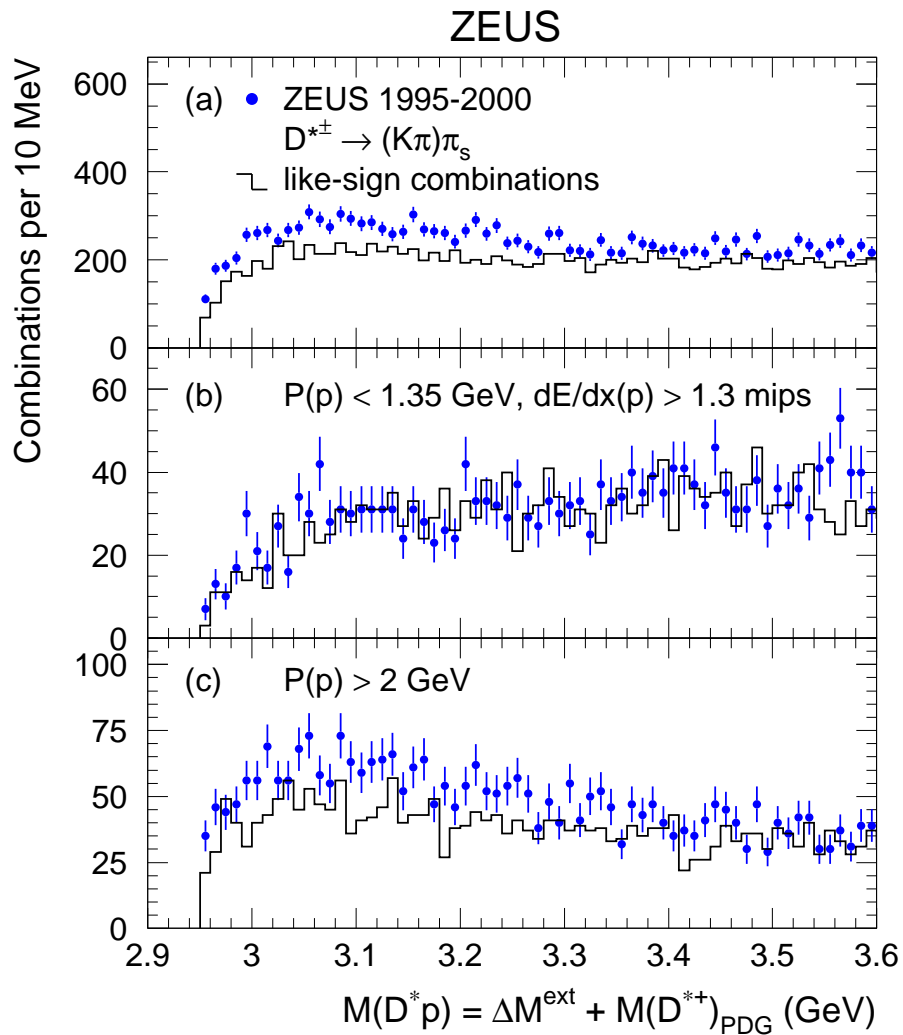
Backup - Θ^+ : Q_{\min}^2 and W binning ...



D^* decay channel	$(K\pi)\pi_s$	$(K\pi\pi\pi)\pi_s$	Both channels
Full data sample			
N_{window}	1710	914	
N_{backgr}	1678 ± 23	919 ± 19	
$N(D^*)$	42680 ± 350	19900 ± 250	
$R(\Theta_c^0 \rightarrow D^*p/D^*)$	$< 0.29\%$	$< 0.33\%$	$< 0.23\%$
$R^{\text{cor}}(\Theta_c^0 \rightarrow D^*p/D^*)$	$< 0.47\%$	$< 0.50\%$	$< 0.37\%$
$f(c \rightarrow \Theta_c^0) \cdot B_{\Theta_c^0 \rightarrow D^*p}$	$< 0.18\%$	$< 0.33\%$	$< 0.16\%$
DIS with $Q^2 > 1\text{GeV}^2$			
N_{window}	252	220	
N_{backgr}	252.8 ± 9.2	219.8 ± 8.8	
$N(D^*)$	8680 ± 130	4830 ± 120	
$R(\Theta_c^0 \rightarrow D^*p/D^*)$	$< 0.41\%$	$< 0.69\%$	$< 0.35\%$
$R^{\text{cor}}(\Theta_c^0 \rightarrow D^*p/D^*)$	$< 0.59\%$	$< 1.06\%$	$< 0.51\%$
$f(c \rightarrow \Theta_c^0) \cdot B_{\Theta_c^0 \rightarrow D^*p}$	$< 0.20\%$	$< 0.56\%$	$< 0.19\%$

Backup - \ominus_c Low/High Momenta

Total Data Sample



DIS Sample

