New Resonances in the hadronic final state at HERA

Katsuo Tokushuku
(KEK, ZEUS)
on behalf of H1 and ZEUS Collaborations

- I think people expect that the main topic in this talk is to report the current status of the pentaquark searches at HERA.

  Of course I will. However, the situation is still unclear. H1 and ZEUS give incoherent results.

  New results from HERA-II data are not yet in public.

- In this talk, I reviews what have been done in HERA-I on resonance (and stable particle) productions, starting from 2 quark states (mesons) to 6 or more quark states.

- q-qbar
- qqq
- qqqq-qbar
- qqqqqq
- .....

Why new resonance searches at HERA?

- This is not the primal physics subject at HERA.
- The detectors are not optimized for particle spectroscopy.
  (e.g. weak particle IDs capabilities. etc.)
- Production rates in the detector acceptance is moderate.
  No chance to beat LEP, B/C/tau-factories.

Still, it is very important to compare ep measurements with the other processes, to see the universality in the hadron productions.

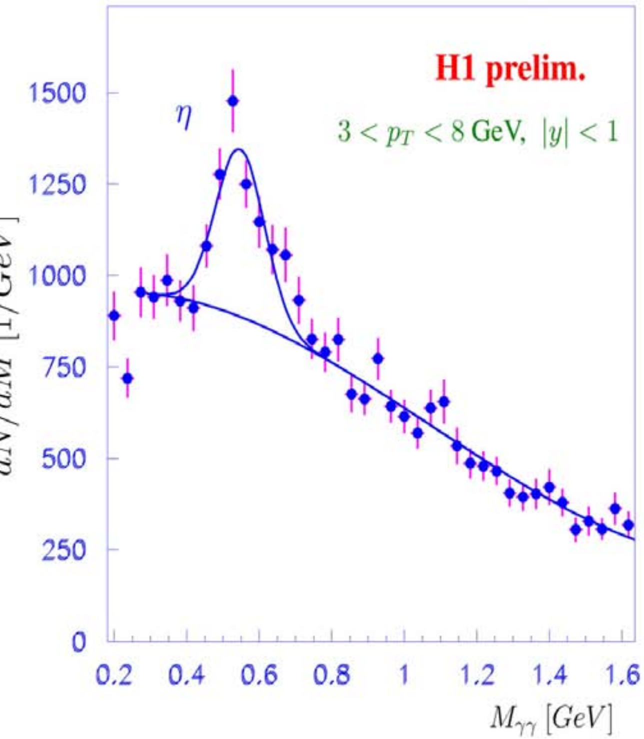
Also, by tagging the scattered leptons, we can study with large range of kinematic regions. (Q^2, x, W, target/current-region....).
-> Gluon-rich region, Quark-rich region, baryon-rich region....
<- though not yet clearly demonstrated.
→ need high statistics, HERA-II

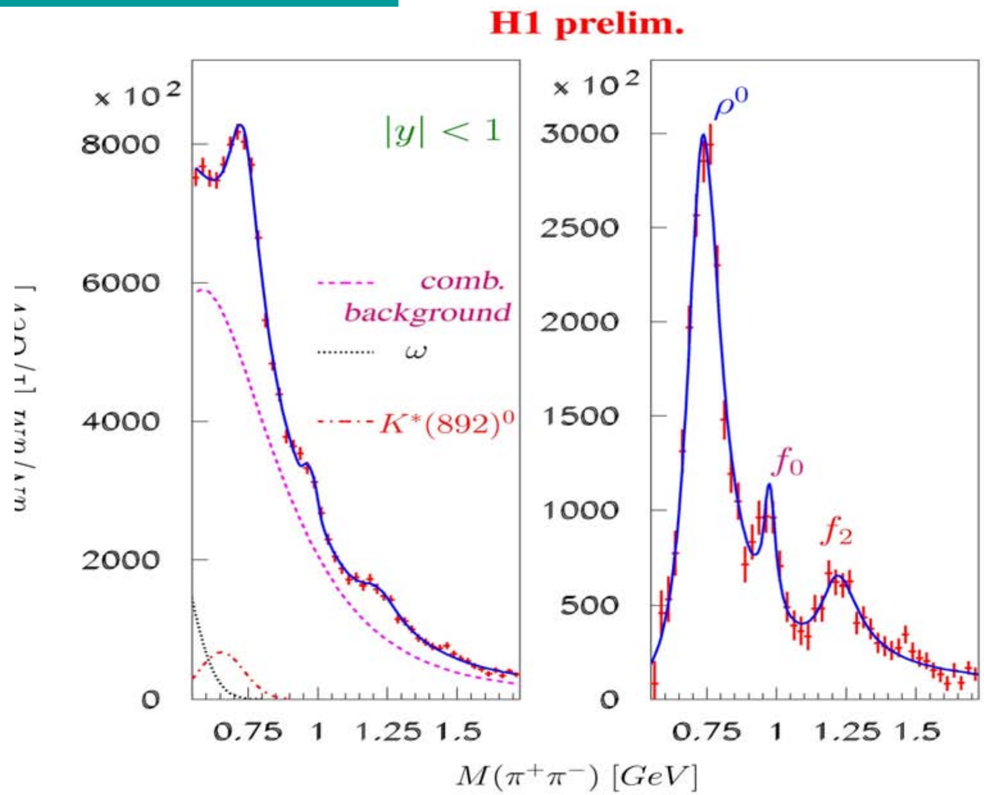
$q\bar{q}$

Heavy quark mesons and diffractively produced vector mesons are not covered in this talk.

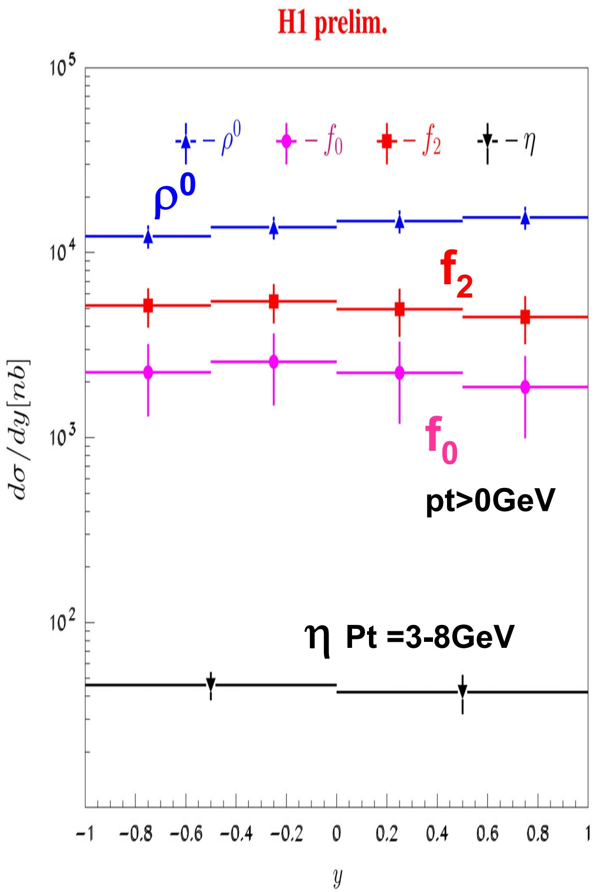
$M\gamma\gamma$

$M\pi^+\pi^-$

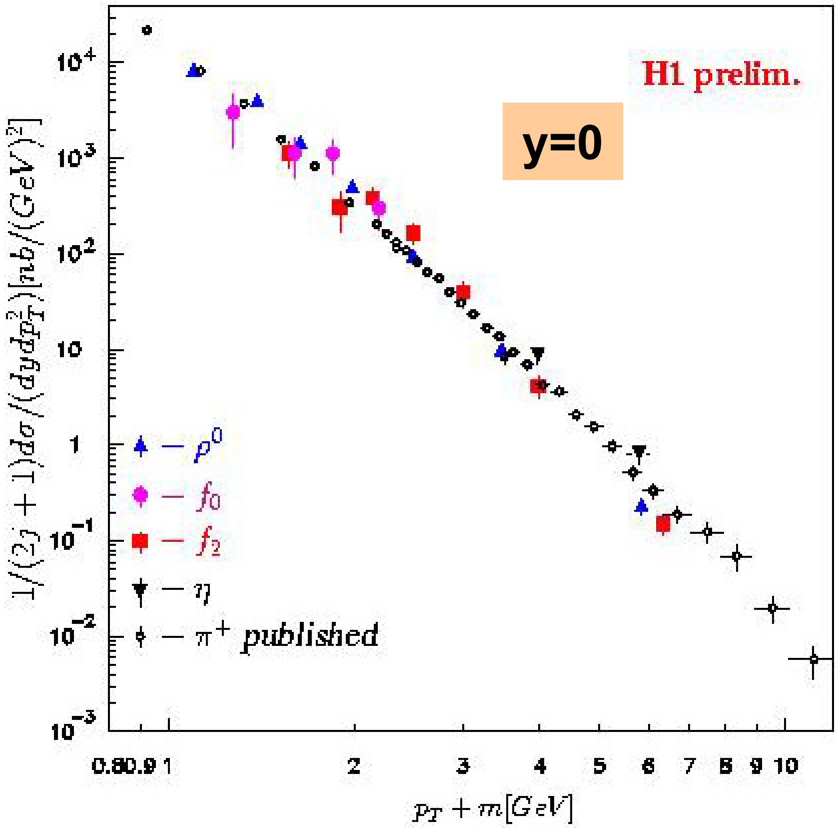




- Photoprocuction
  ($Q^2<10^{-2}GeV^2$)
- 174<W<256 GeV
- -1 < y <1



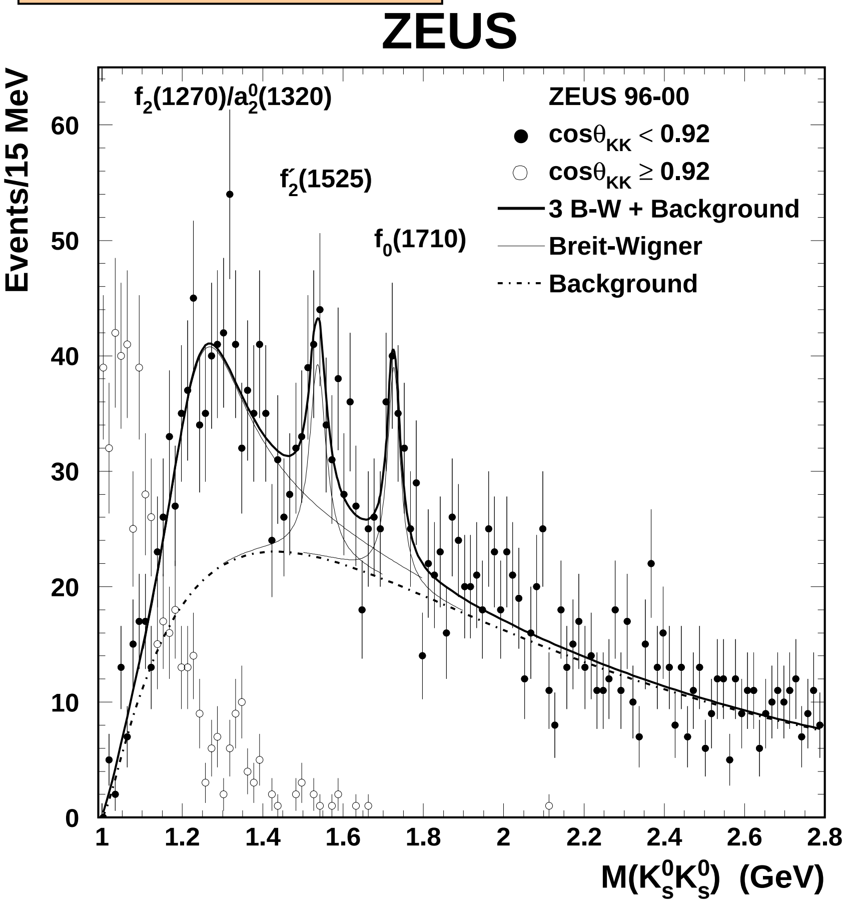
Flat rapidity distribution



Universal Pt distribution
when plotting with pt+m (instead of pt)
→ Thermodynamic picture may work

$M_{K^0K^0}$

- Q^2>a few GeV^2
- 50<W<250 GeV



- Low K^0K^0 mass region is suppressed by requiring cos θ_{KK} <0.92
  (Opening angle of the two K0's)

- 3 peaks are seen.
  $M = 1274^{+17}_{-16}$ MeV $\Gamma = 244^{+85}_{-58}$ MeV
  broad peak ($f_2(1270)/a_2(1320)$)

  $M=1537^{+9}_{-8}$ MeV $\Gamma=50^{+34}_{-22}$ MeV
  consistent with $f_2'(1525)$

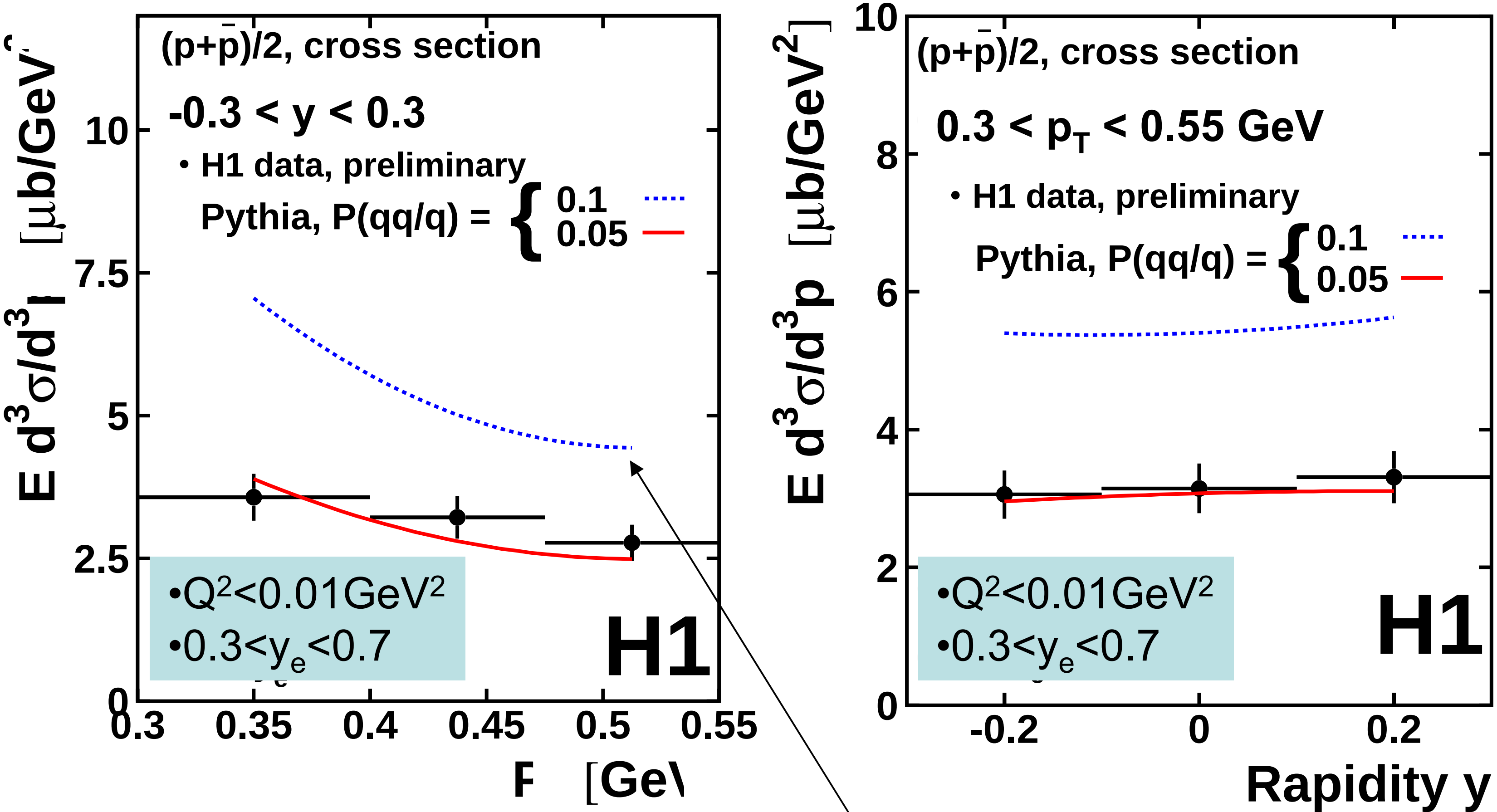
  $M=1726^{+7}_{-7}$ MeV $\Gamma=38^{+20}_{-14}$ MeV
  f0(1710) ?
  (PDG Γ=125 +-10MeV)
  a glueball candidate.

Many (93%) kaons are in the target region of the Breit frame.
→ Gluon rich region

HERA-II high statistic data will help to check the production mechanism.

qqq

Proton

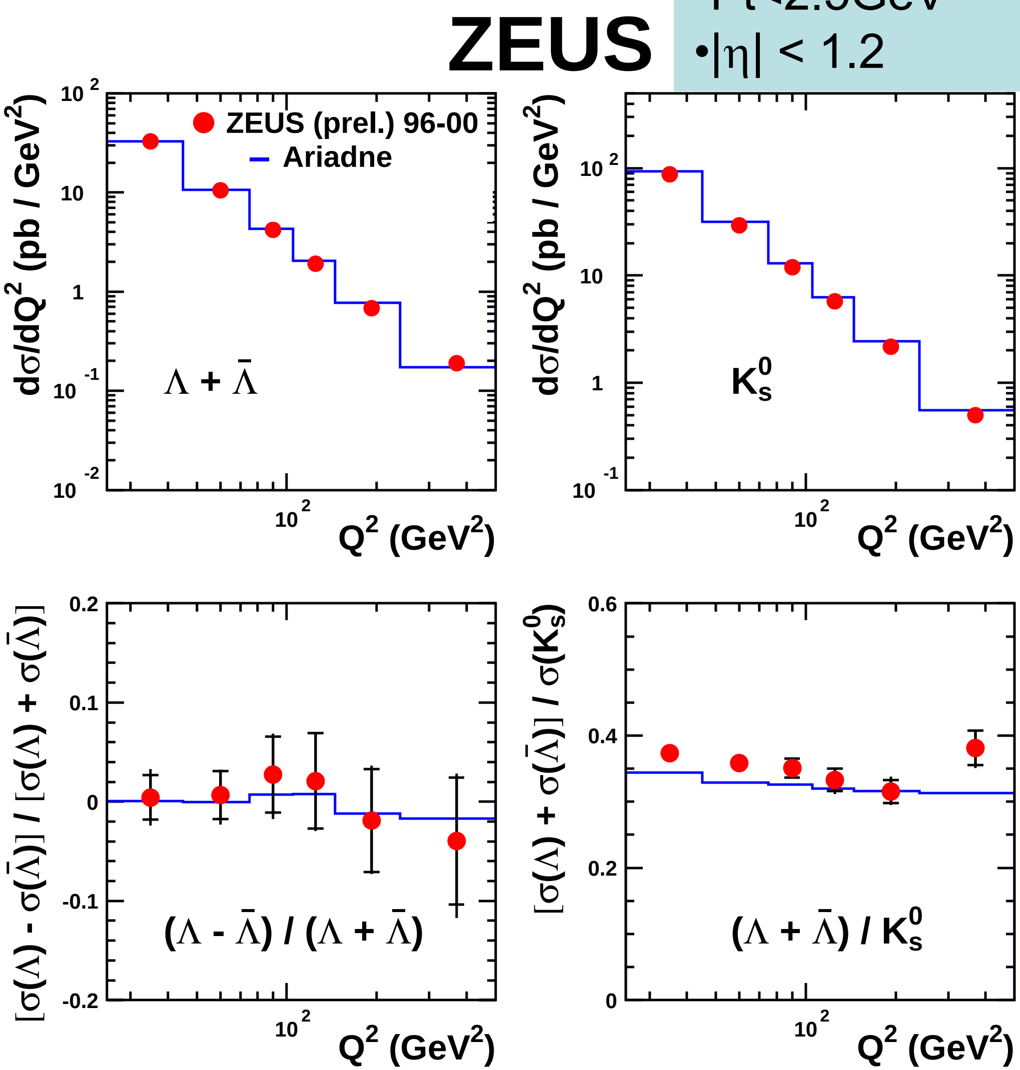


Shape agrees with Pythia.
But absolute rate is a factor 2 lower

Favoured by LEP

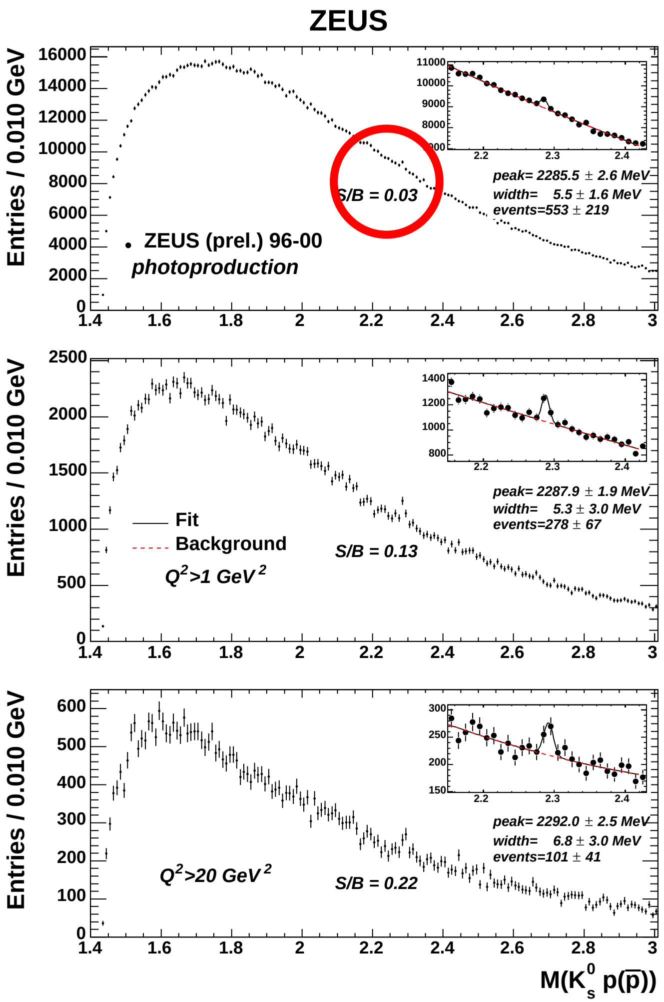
Lambda

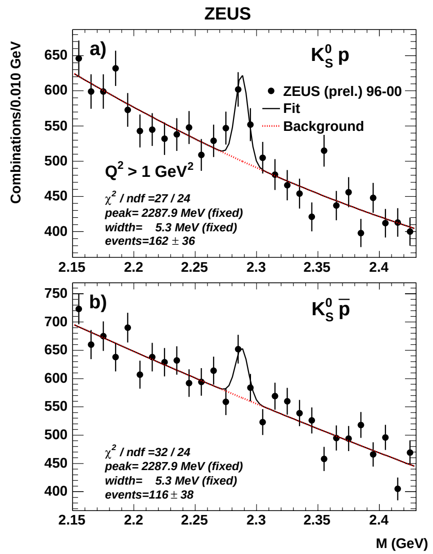
- Q^2>25 GeV^2
- 0.02<y<0.95
- Pt<2.5GeV
- |η| < 1.2



- Reasonable agreement with MC.
  (small deviation in Λ/K0 at low-x and low Pt (not shown))
- Λ/Λ̄ ~ 1
  : no significant baryon asymmetry in this kinematical region.

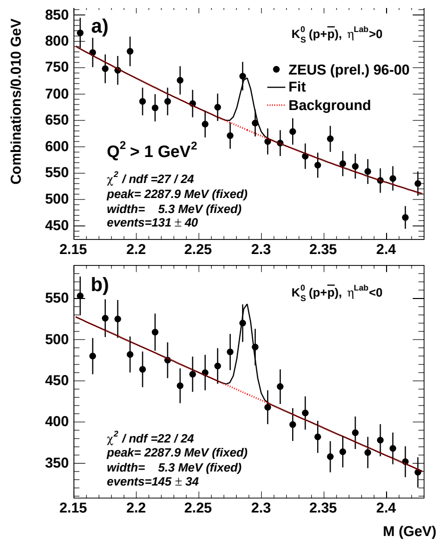
Λc





Λc

$\overline{\Lambda c}$



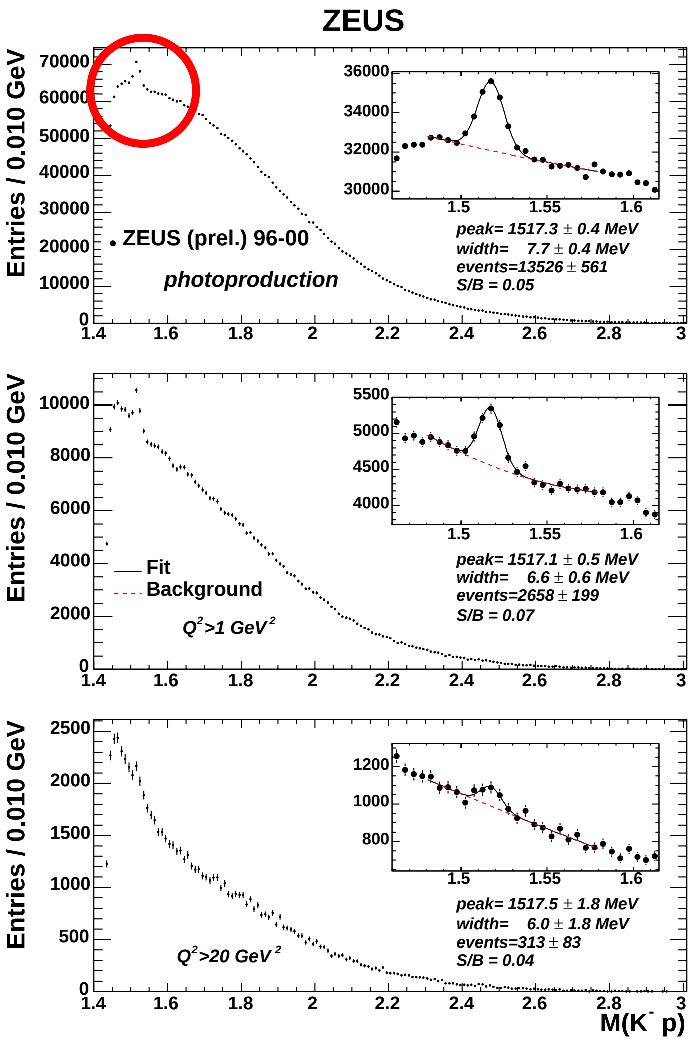
Forward ($\eta_{lab}>0$)

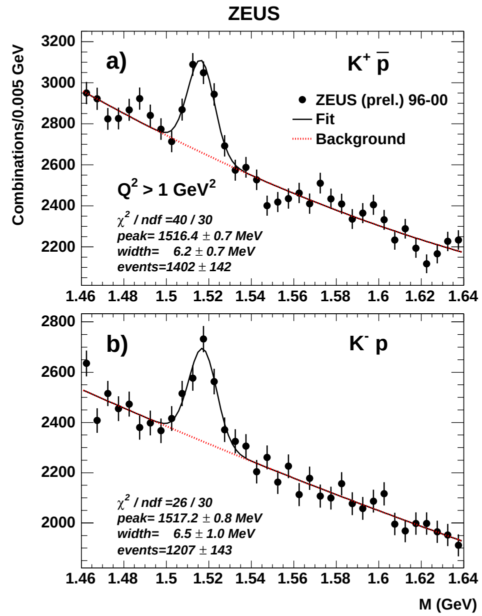
Backward ($\eta_{lab}<0$)

Mass (K^0 p) or (K^0 $\bar{p}$)

No baryon asymmetry.
No FWD/BWD asymmetry

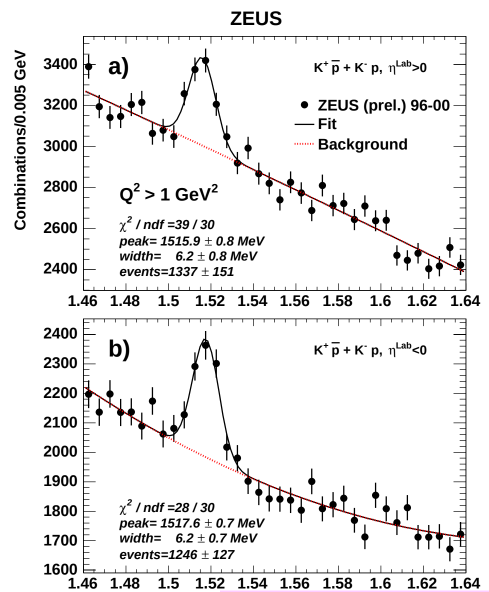
Λ(1520)





$\overline{\Lambda^*}$

Λ^*



Forward (η_{lab}>0)

Backward (η_{lab}<0)

Mass (K$^-$ p) or (K$^+$ $\bar{p}$)

No baryon asymmetry.
No FWD/BWD asymmetry

qqq summary

- Many baryons are observed in the central detectors.
- No significant baryon anti-baryon asymmetry is observed in the measured area
    - rapidity in lab-frame : from ~ -1.5 to ~ 1.5
    - In the Breit frame,
      both current- and target- regions are in acceptance
    - Where do we see the effect of initial baryon?

      : No answers yet
- Is ep baryon production mechanism is different from e^+e^-?

  No answers, yet. There are some differences in some measurements (proton cross section, Λ/K ratio). But it is difficult to get physics insights from comparisons with models with many parameters.

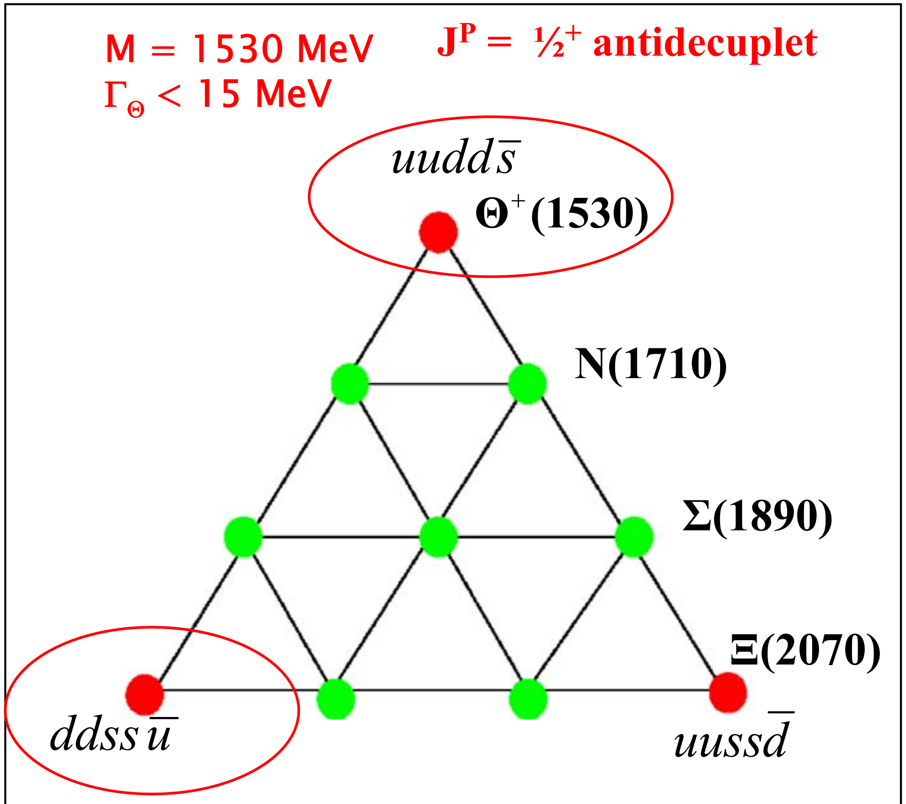
More systematic studies are desirable with High statistic HERA-II data.

$qq\bar{q}\bar{q}$

No HERA results so far

$qqqq\bar{q}$

Pentaquarks



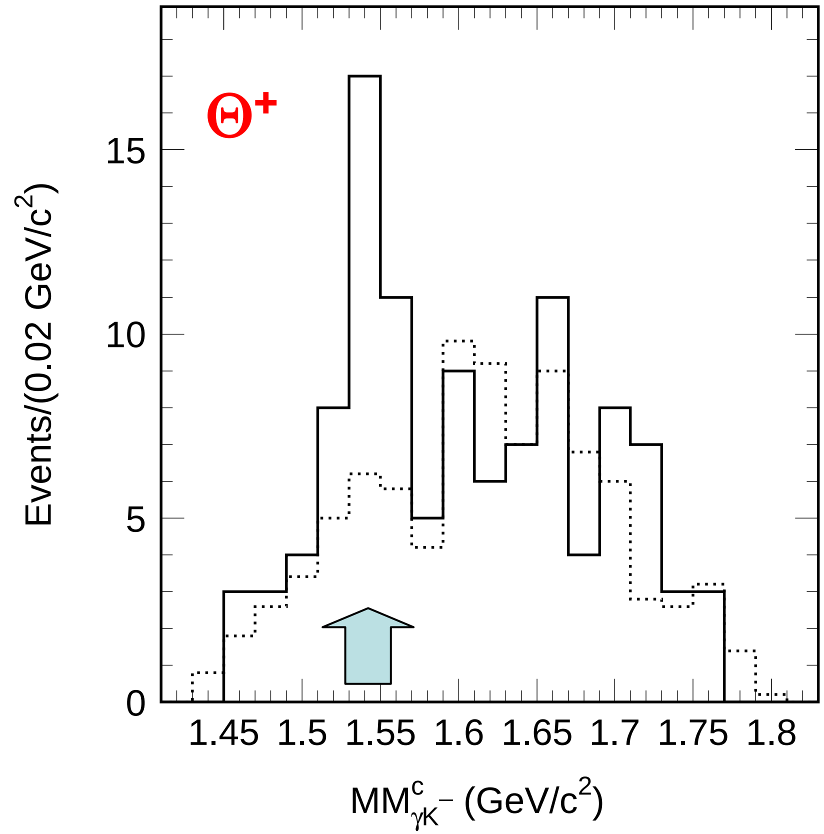
D.Diakonov et al. Z. Phys A359, 1997, 305

D. Diakonov, V. Petrov, Phys. Rev. D69, 2004, 094011

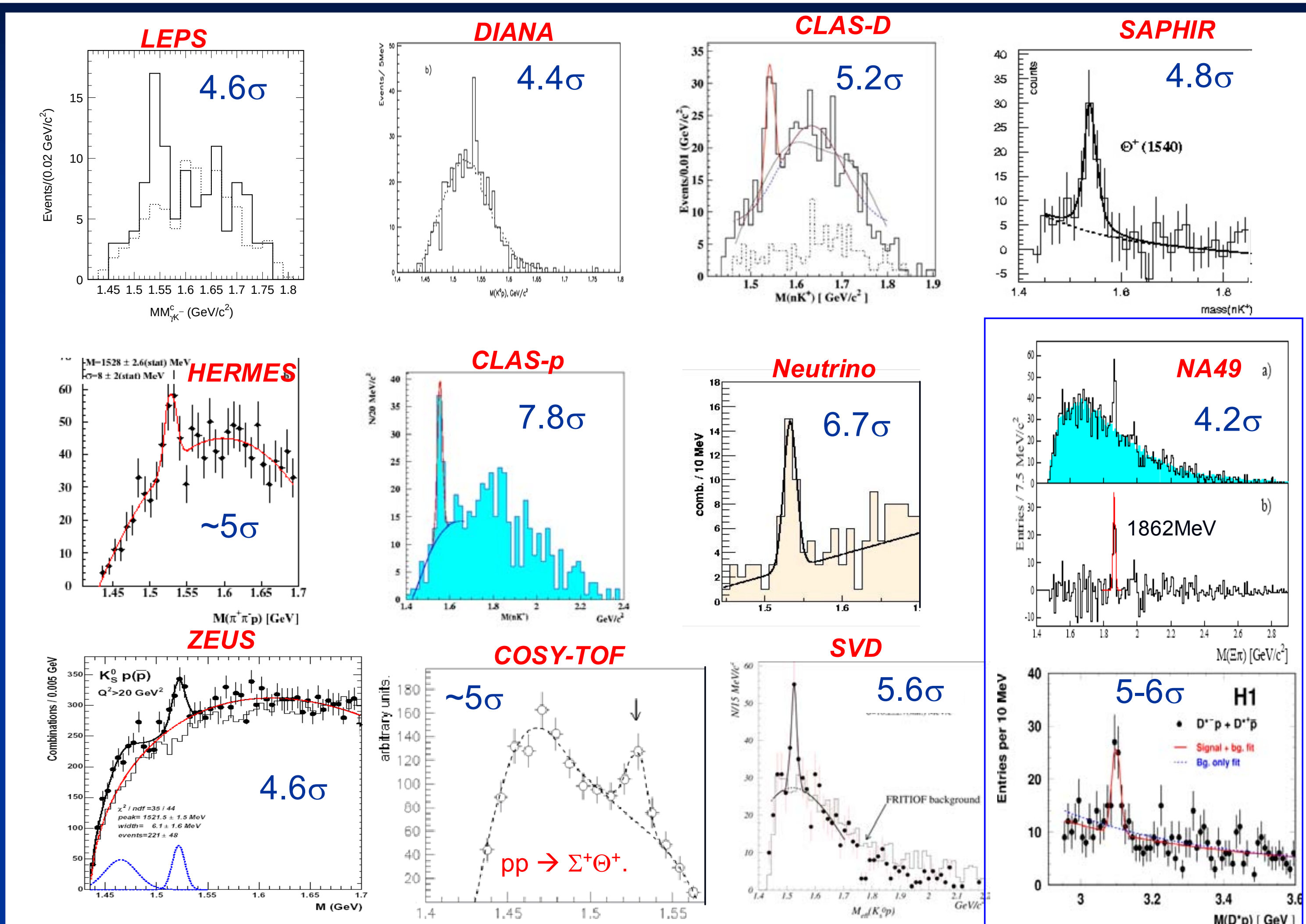
T. Nakano et al.

(LEPS experiment at SPring8)

Phys.Rev.Lett. 91 (2003) 012002
hep-ex/0301020



The initial evidence for Pentaquarks



This slide is taken from LP2005 talk by V. Burkert (J-Lab)

Non-observation of Θ^+

Group	Reaction	Limit
BES	$e^+e^- \to J/\Psi \to \Theta\bar{\Theta}$	$< 1.1 \times 10^{-5}$ B.R.
Belle	$e^+e^- \to B^0B^0 \to pp\bar{K}^0X$	$< 2.3 \times 10^{-7}$ B.R.
BaBar	$e^+e^- \to \Upsilon(4s) \to pK^0X$	$< 1.0 \times 10^{-4}$ B.R.
HERA-B	$pA \to K^0pX$	$\Theta/\Lambda^* < 0.02$
CDF	$p\bar{p} \to K^0pX$	$\Theta/\Lambda^* < 0.03$
PHENIX	$Au + Au \to K^- nX$	not given
SPHINX	$pC \to \Theta^+\bar{K}^0 X$	$\Theta^+K^0/\Lambda^*K^+ < 0.02$
HyperCP	$pA \to \Theta^+\bar{K}^0 X$	$\Theta^+/pK^0 < 0.002$

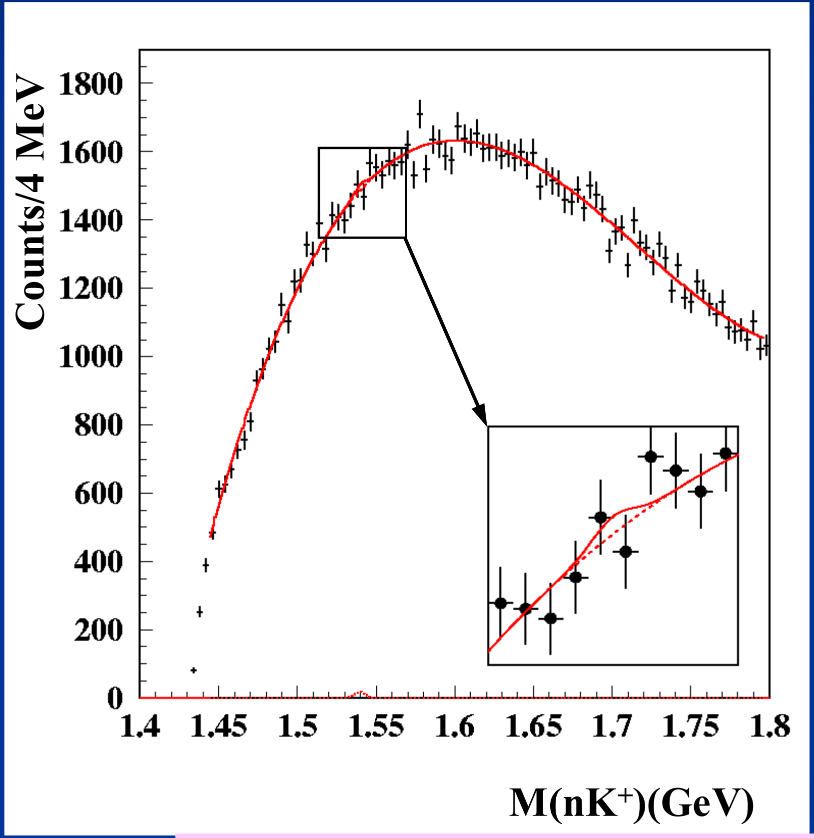
+ unpublished results

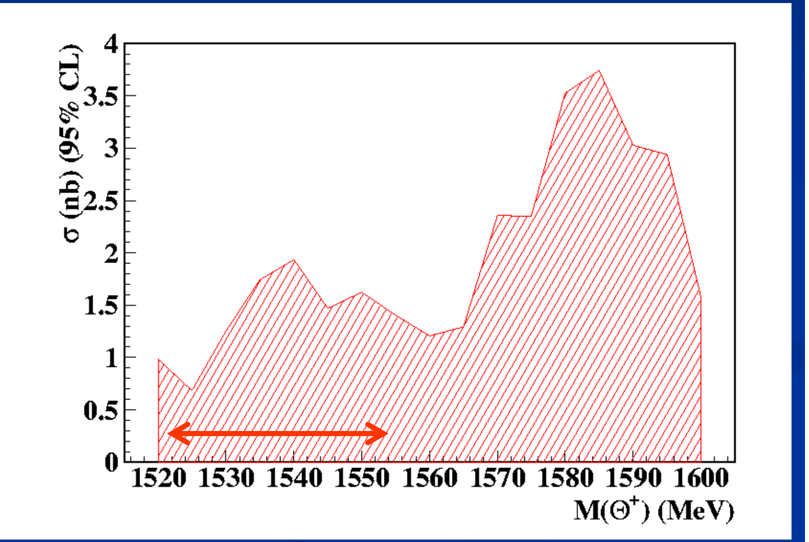
This slide is taken from LP2005 talk by V. Burkert (J-Lab)

CLAS – 2nd Generation Experiment I

$\gamma p \to K_S K^+ n$

LP2005 342





Upper limits (95% CL) :

$\sigma_{\gamma p \to \Theta^+ K^0}$ < 2 nb @ 1520 – 1555 MeV

< 4 nb @ 1560 – 1600 MeV

This slide is taken from LP2005 talk by V. Burkert (J-Lab)

CLAS – 2nd Generation Experiment II

$\gamma D \rightarrow K^- p K^+ n$

LP2005 357

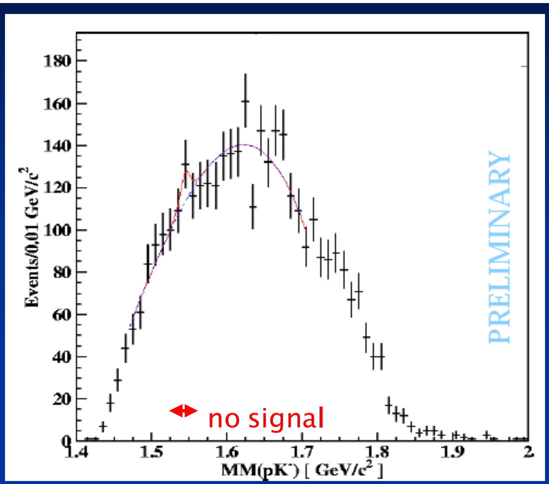
- The new data show no signal

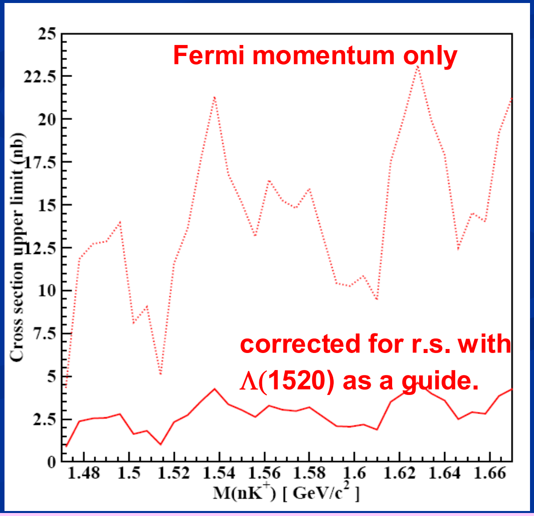
$\Rightarrow$ Set upper limit on cross section

$\gamma n \rightarrow \Theta^+ K^-$

$\sigma_{\Theta^+} < 5$ nb (95% CL)
model dependent.

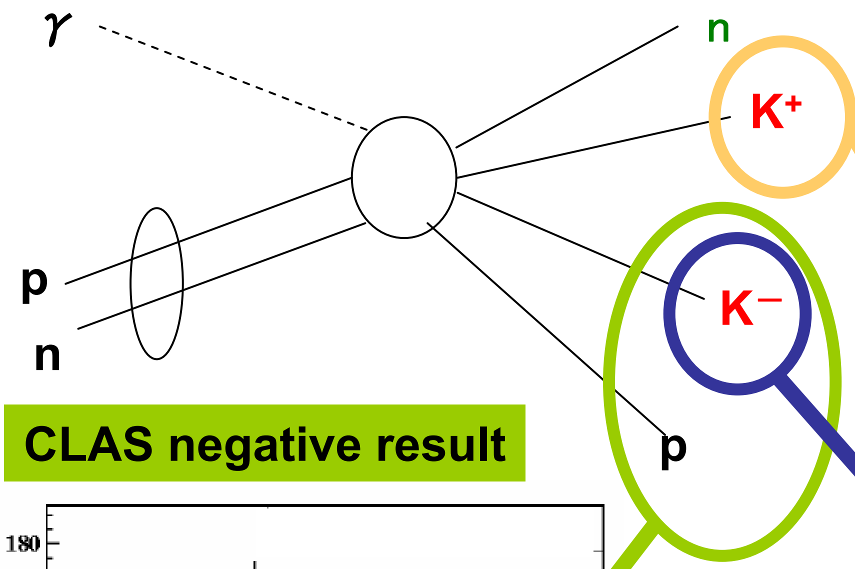
- In previous result the background is underestimated. New estimate of the original data gives a significance of $\sim 3\sigma$, possibly due to a fluctuation.



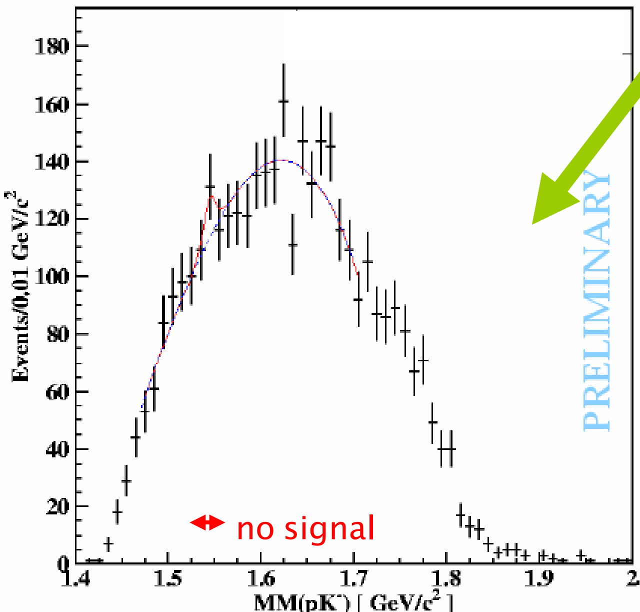


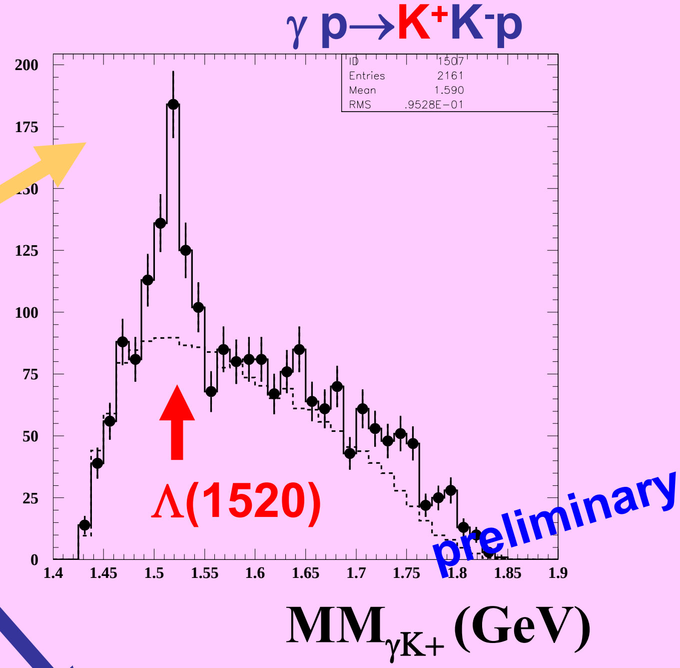
This slide is taken from LP2005 talk by V. Burkert (J-Lab)

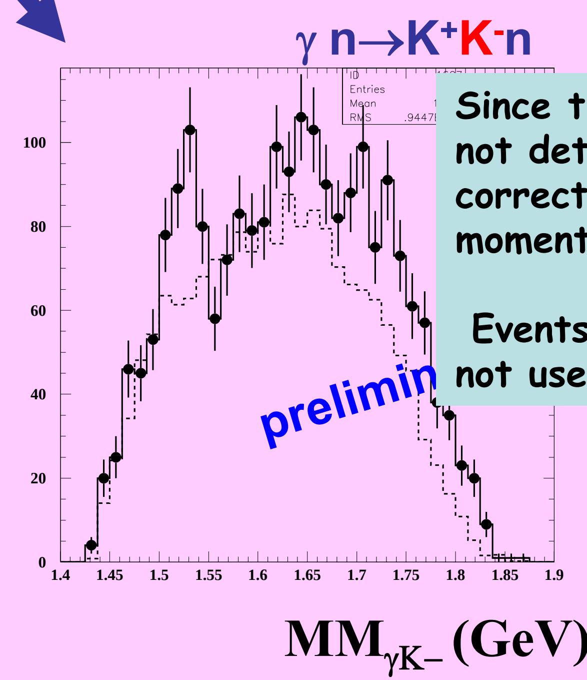
New Positive results from LEPS (γd)



CLAS negative result







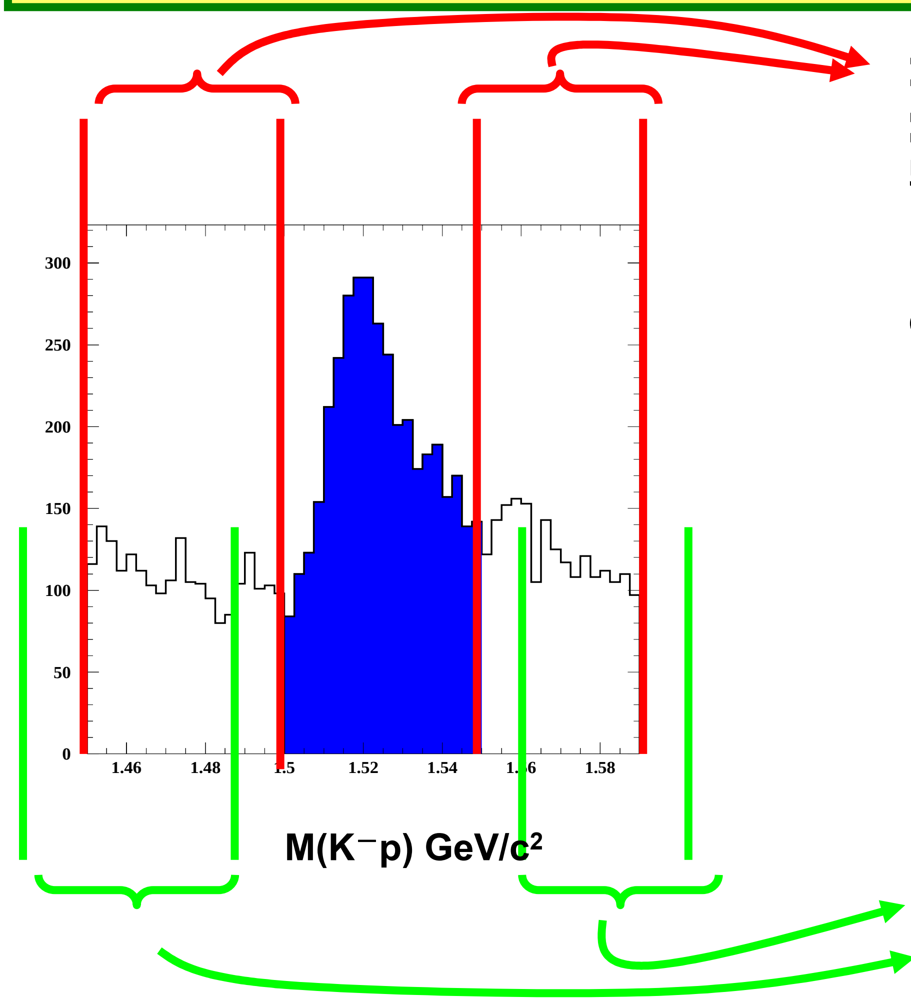
Since the proton is not detected, a correction for Fermi momentum is included.

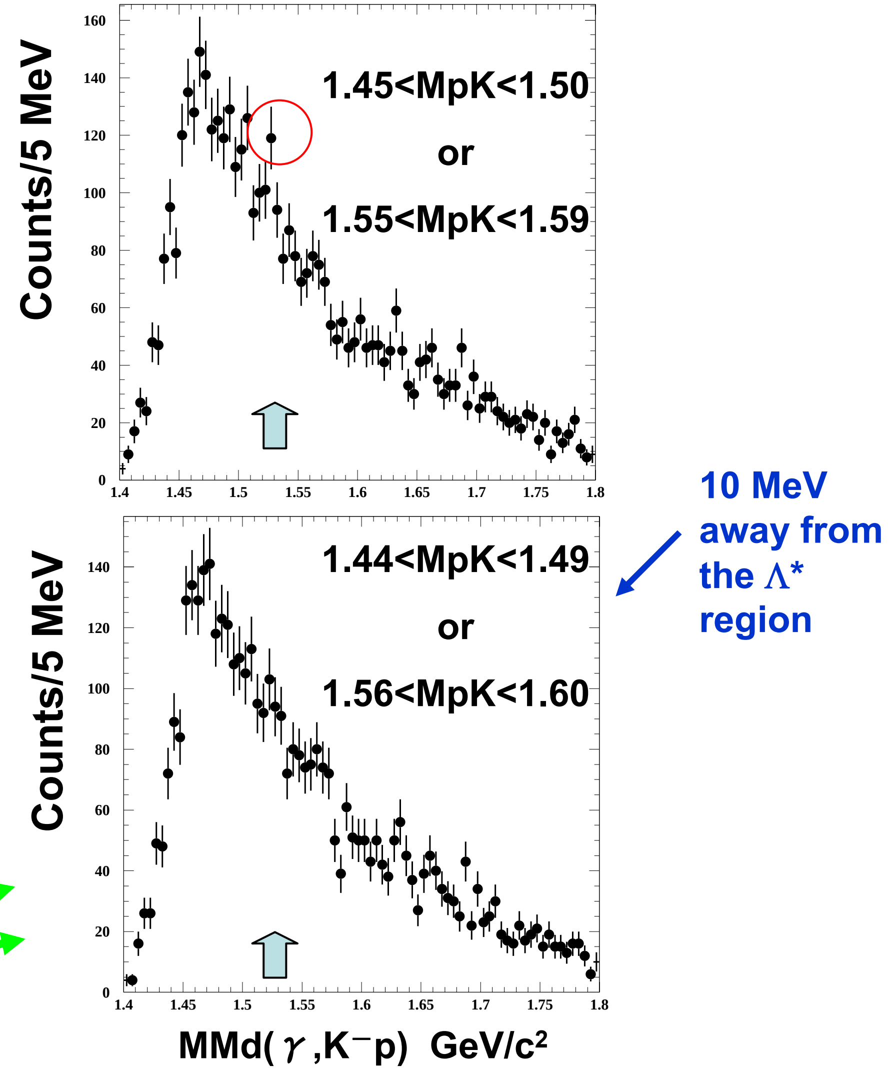
Events with phi are not used.

CLAS uses events with p and K⁻, while theseLEPS's plots are K⁻ and K⁺.
-> Different kinematical region

Plots shown by T.Nakano (Osaka) in APS/JPS meeting

K⁻p mass and K⁻p missing mass in sideband regions



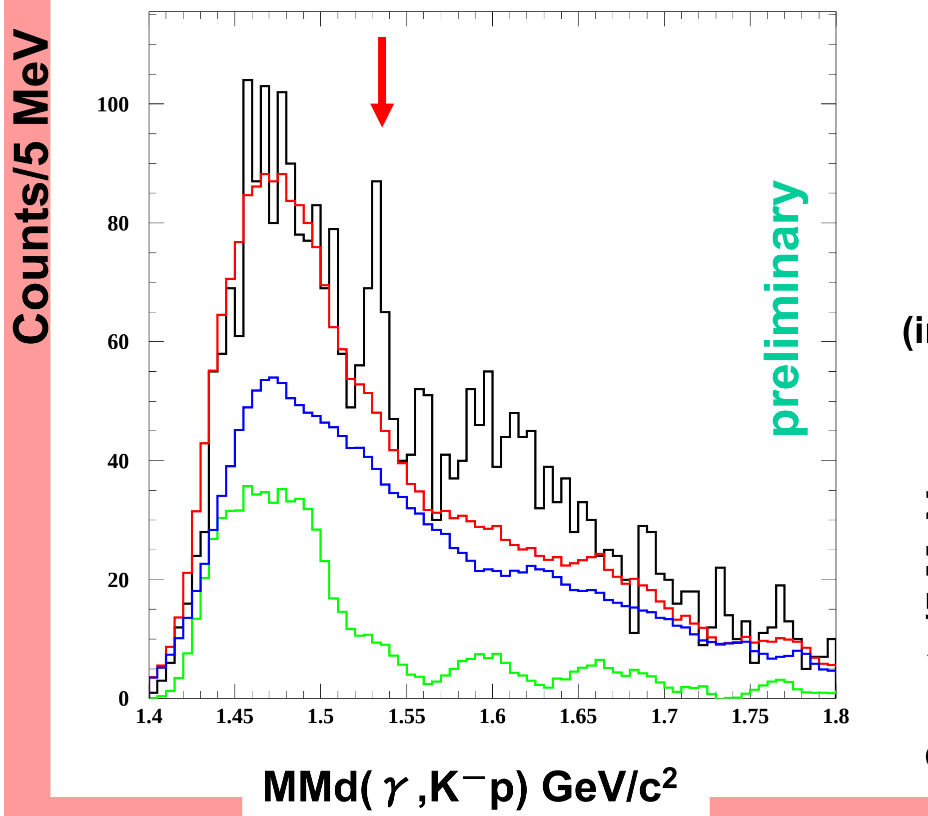


In K⁻P mass spectra, clear Λ(1520) peak is observed.
MM plots way from Λ(1520) has no Θ⁺ signal

K.Tokushuku

Plots shown by T.Nakano (Osaka) in APS/JPS meeting

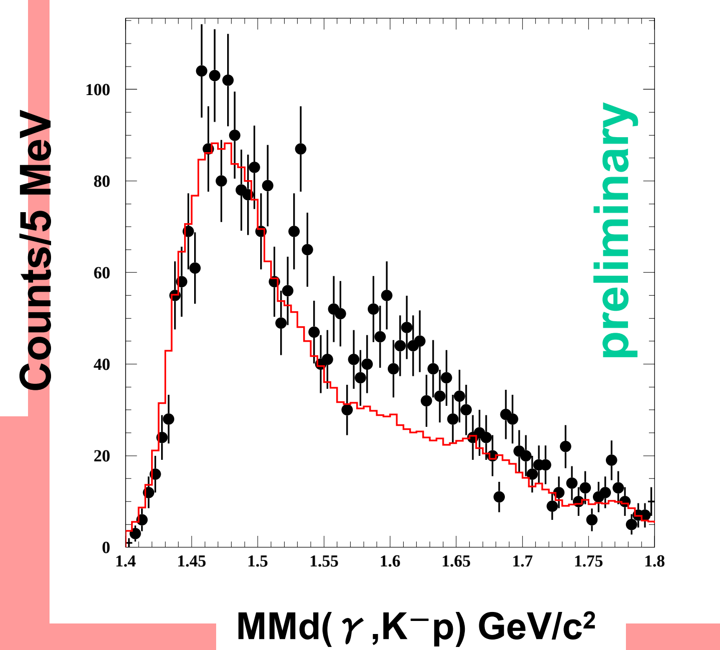
K⁻p missing mass spectrum on Λ(1520)



Excesses are seen at 1.53 GeV and at 1.6 GeV above the background level.

1.53-GeV peak: $\frac{S}{\sqrt{S+B}} \approx 5$

(in the 5 bin = 25 MeV)



sideband

Λ*

sum

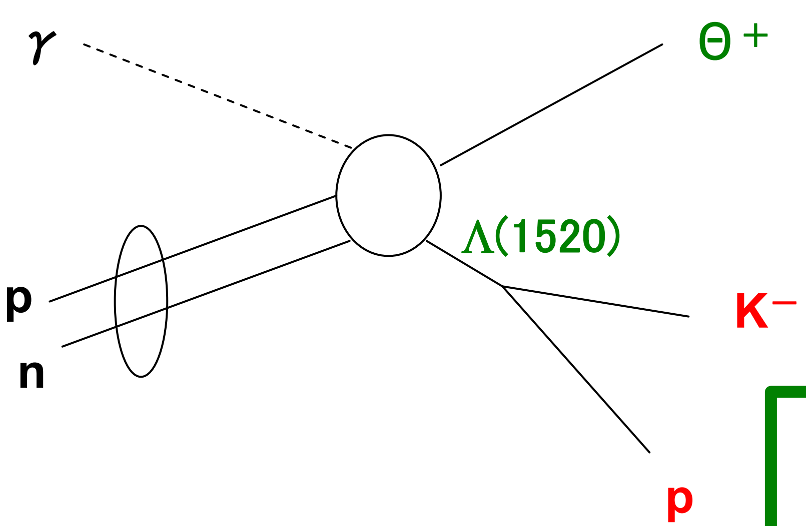
Normalization of Λ* is obtained by fit in the region of MMd < 1.52 GeV.

Plots shown by T.Nakano (Osaka) in APS/JPS meeting

New results from LEPS indicates the associate production is a favorable mechanism.

$\gamma + d \rightarrow \Theta^{+} + \Lambda^{*}(1520)$

But it is not known if this is the main mechanism or not, since all plots are "raw" distributions. (There acceptance for Λ^{*} is high)



It is very unlikely to happen at ep collision in HERA energy range....

N.B. Another new positive result from SVD collaboration (70GeVpA reactions, mass(K0p)) (hep-ex0509033)

3

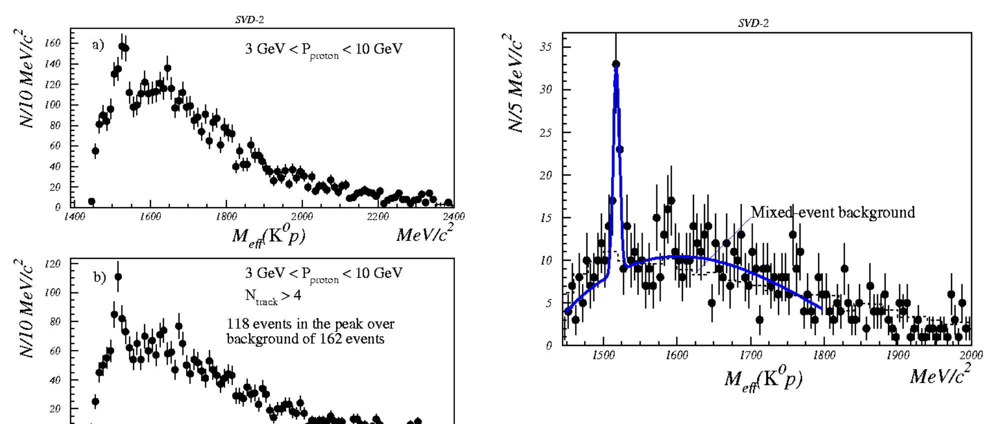
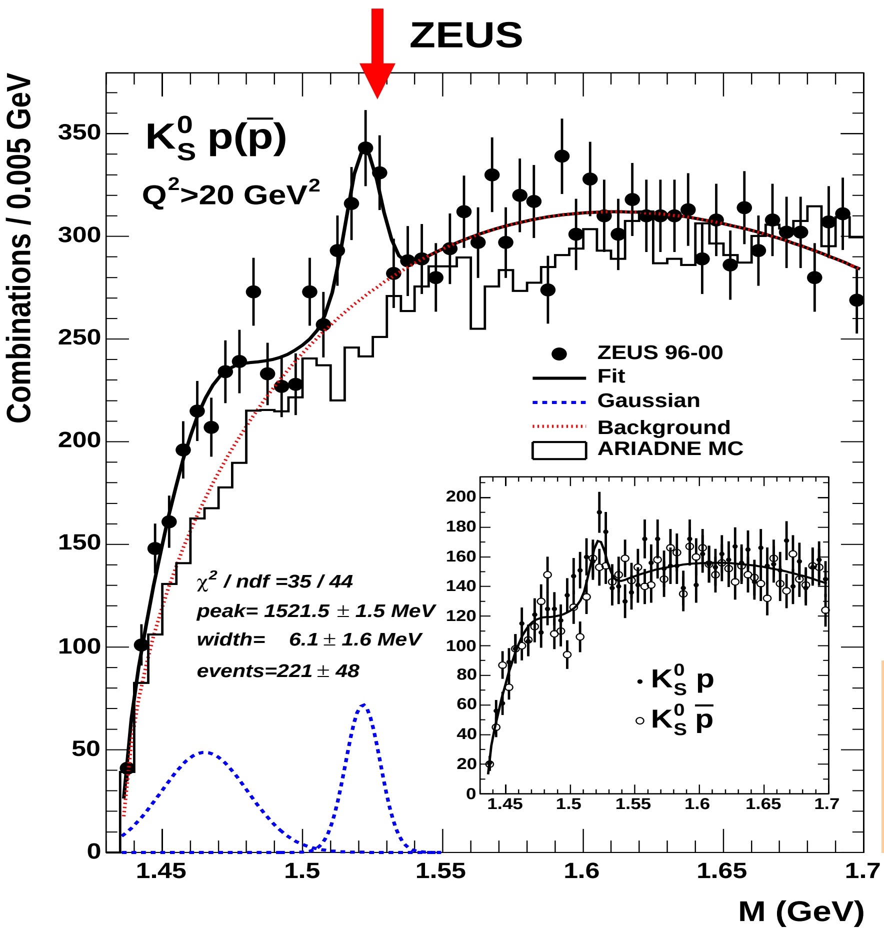
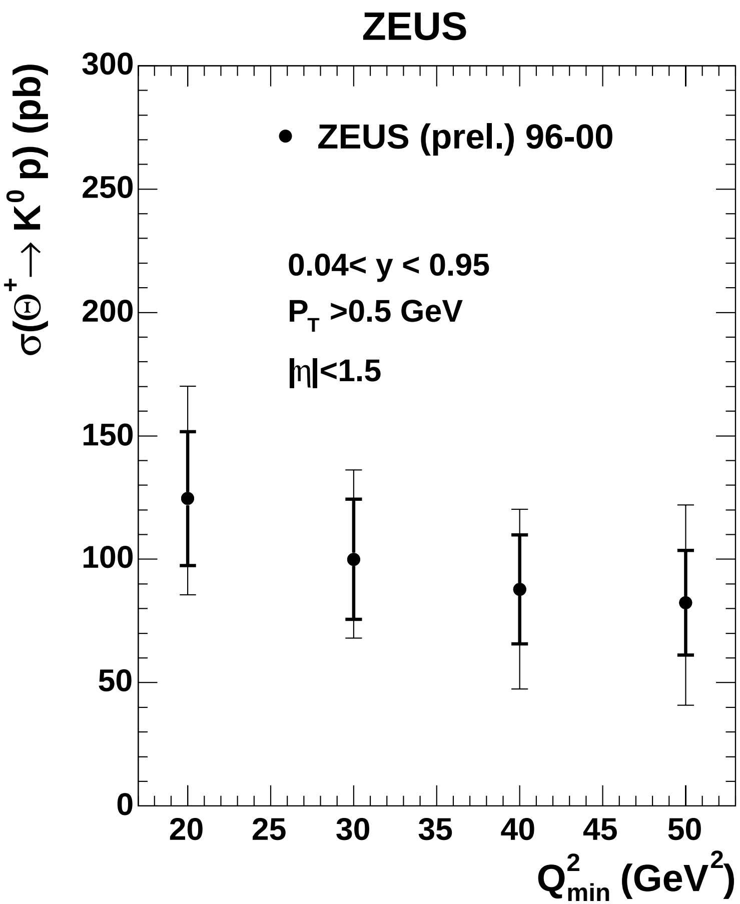


FIG. 4: Analysis I: The (pK_s^0) invariant mass spectrum fo K_s^0 decaying inside the vertex detector with additional qualit cuts explained in text.

FIG. 3: Analysis I: The (pK_s^0) invariant mass spectrum for K_s^0

Pentaquark search at ZEUS/H1

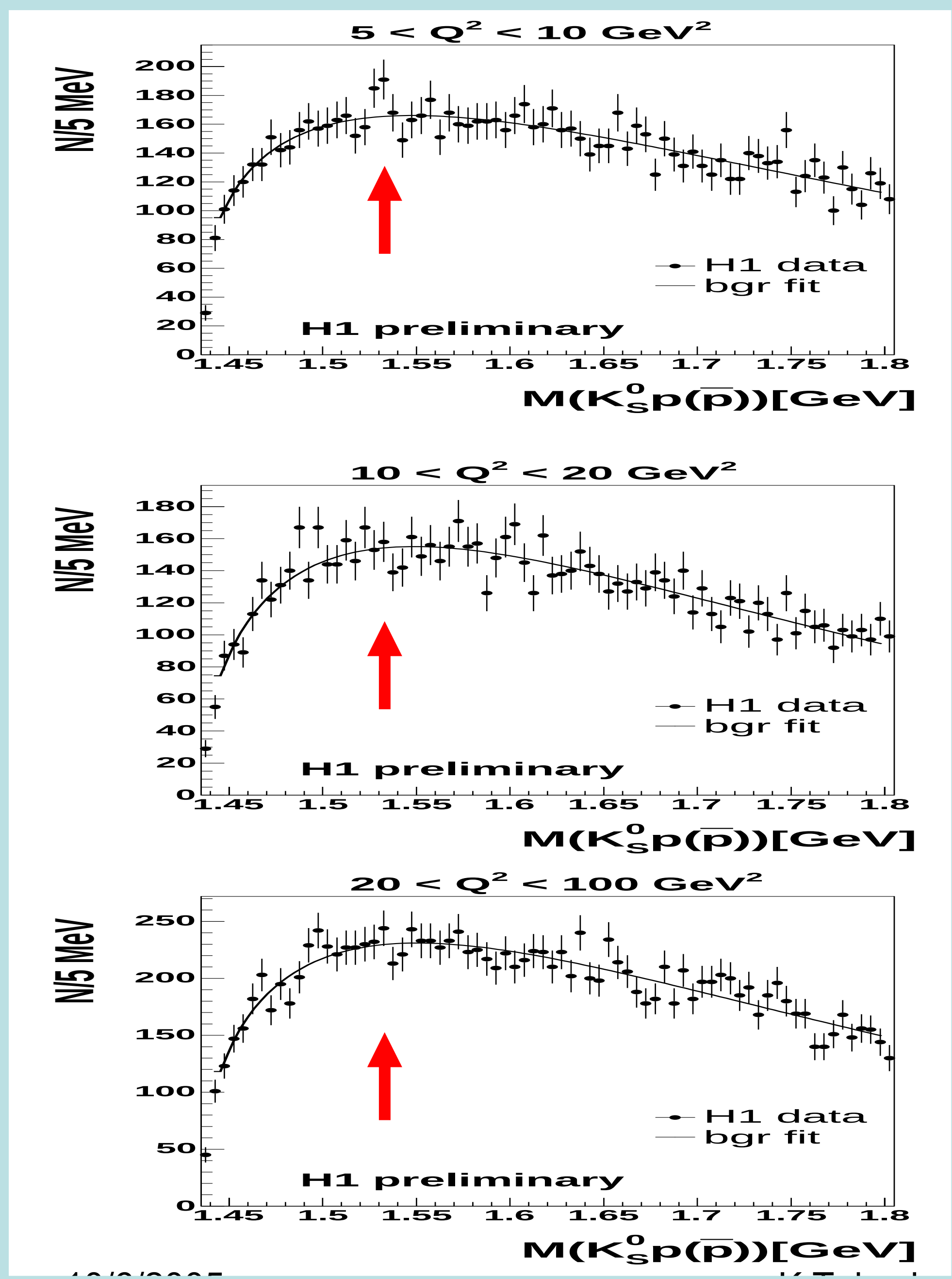


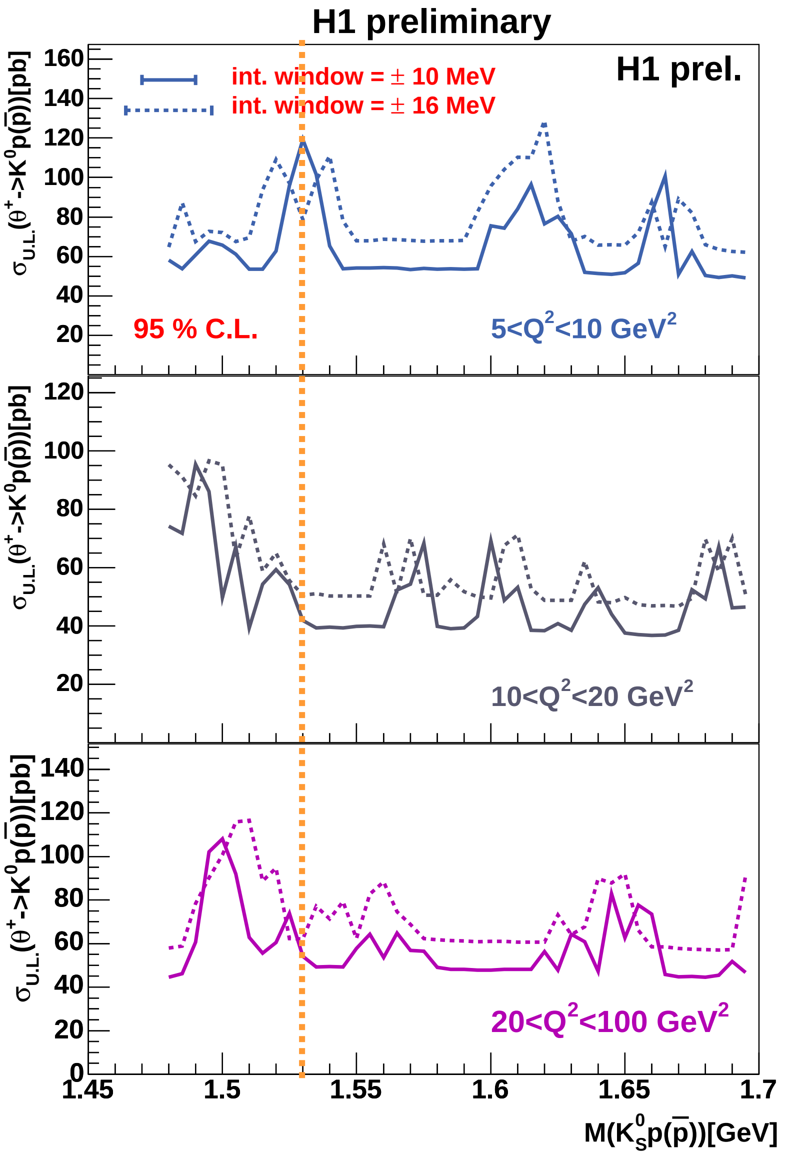


$\sigma(\Theta)/\sigma(\Lambda)$ ~ 0.05

: Θ is not seen in LEP

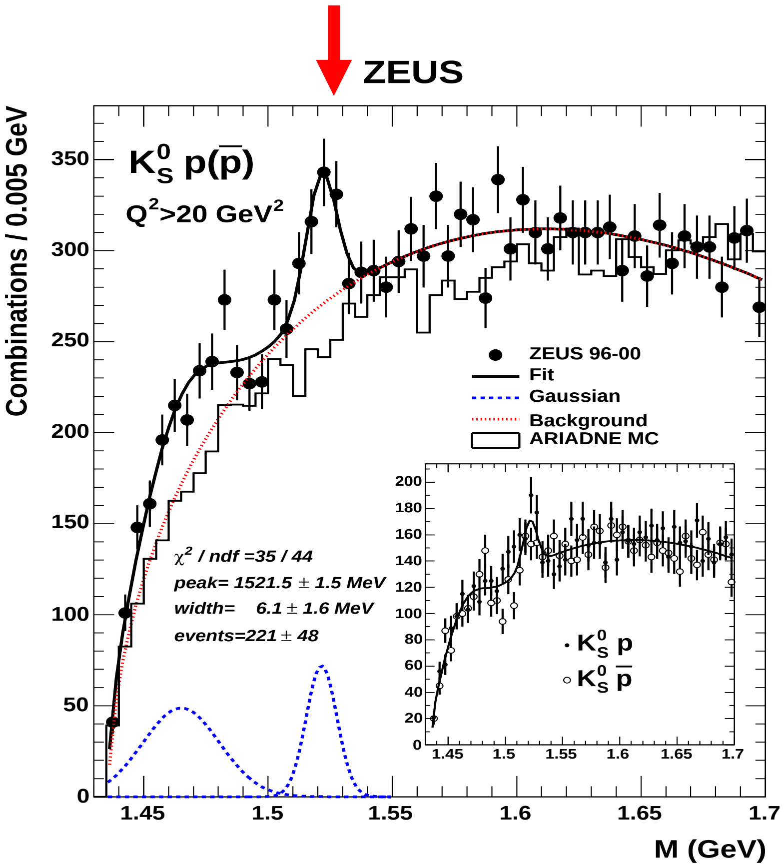
→ different production mechanism?

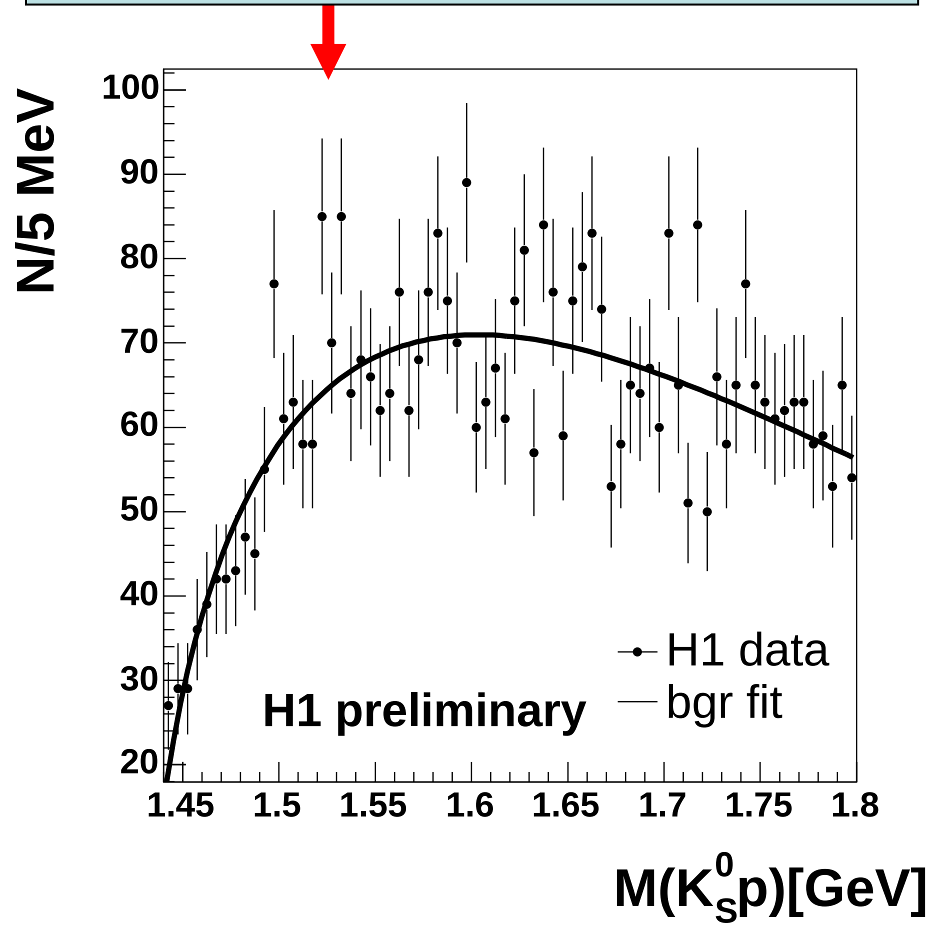


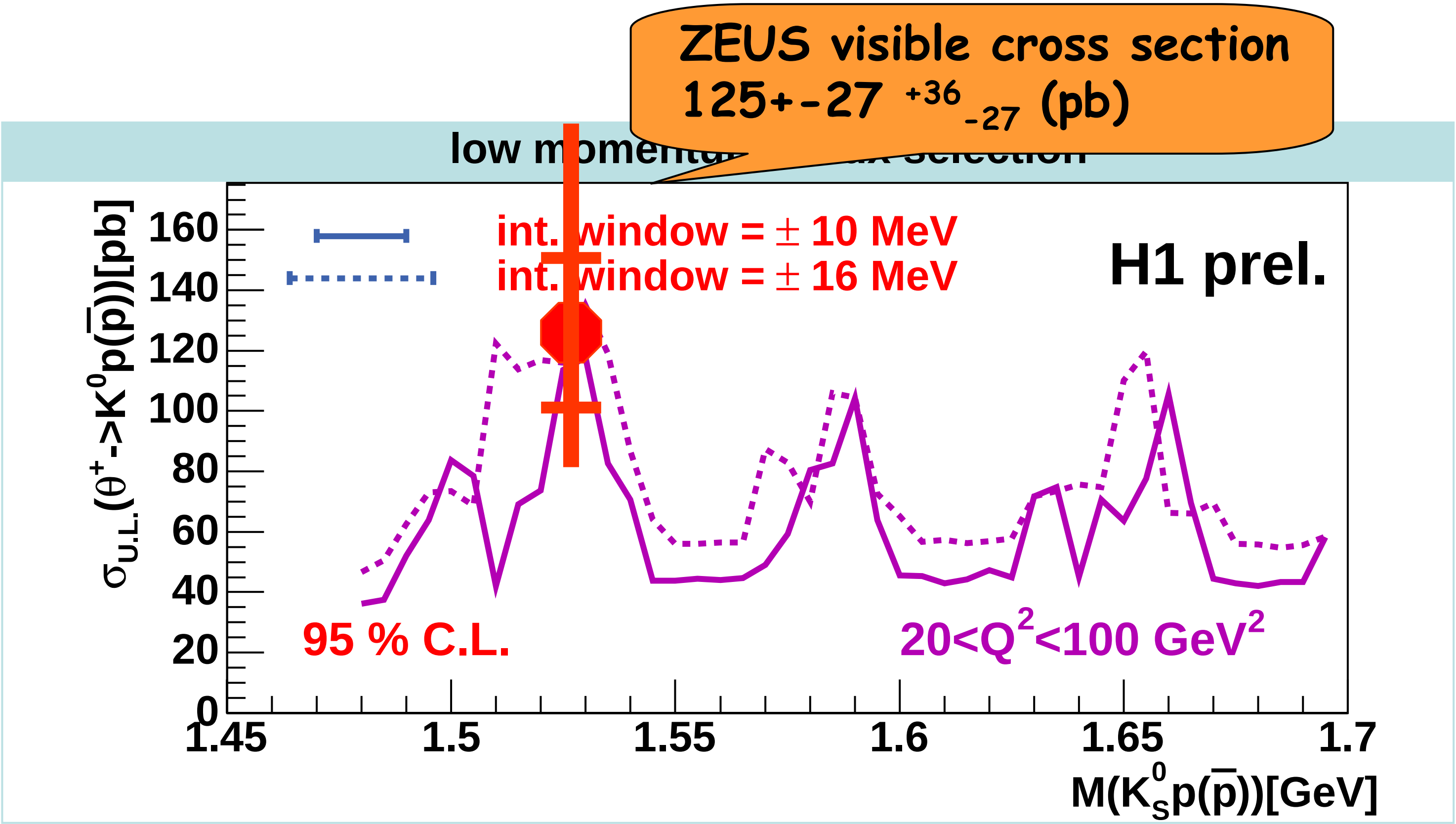


H1 :
no significant peak in Θ region

H1: with ZEUS-like event selection (p_p < 1.5GeV)





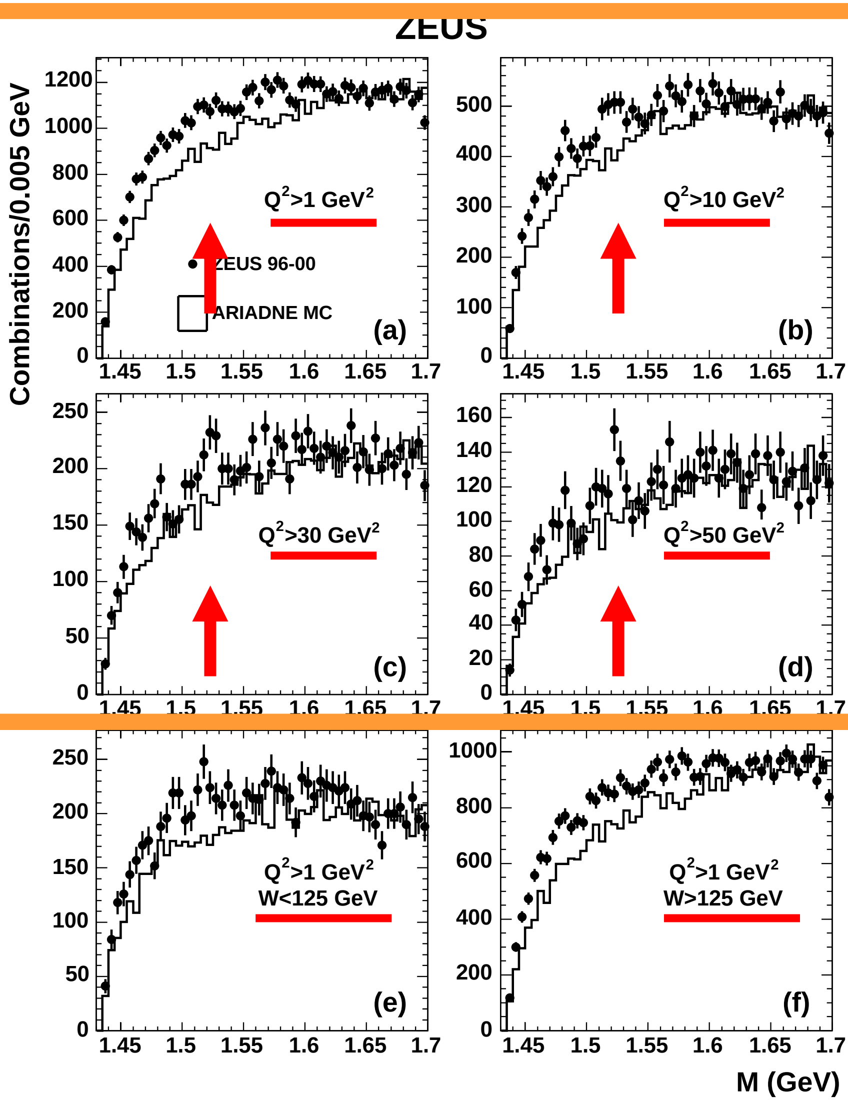


The two measurements are still compatible.

→

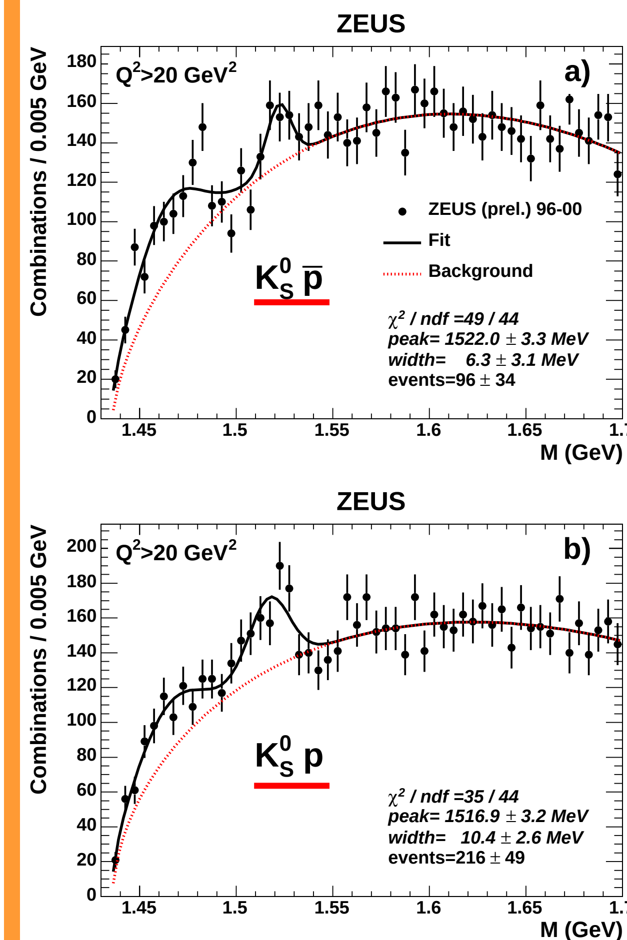
We need higher statistics HERA-II data

Θ properties (ZEUS)



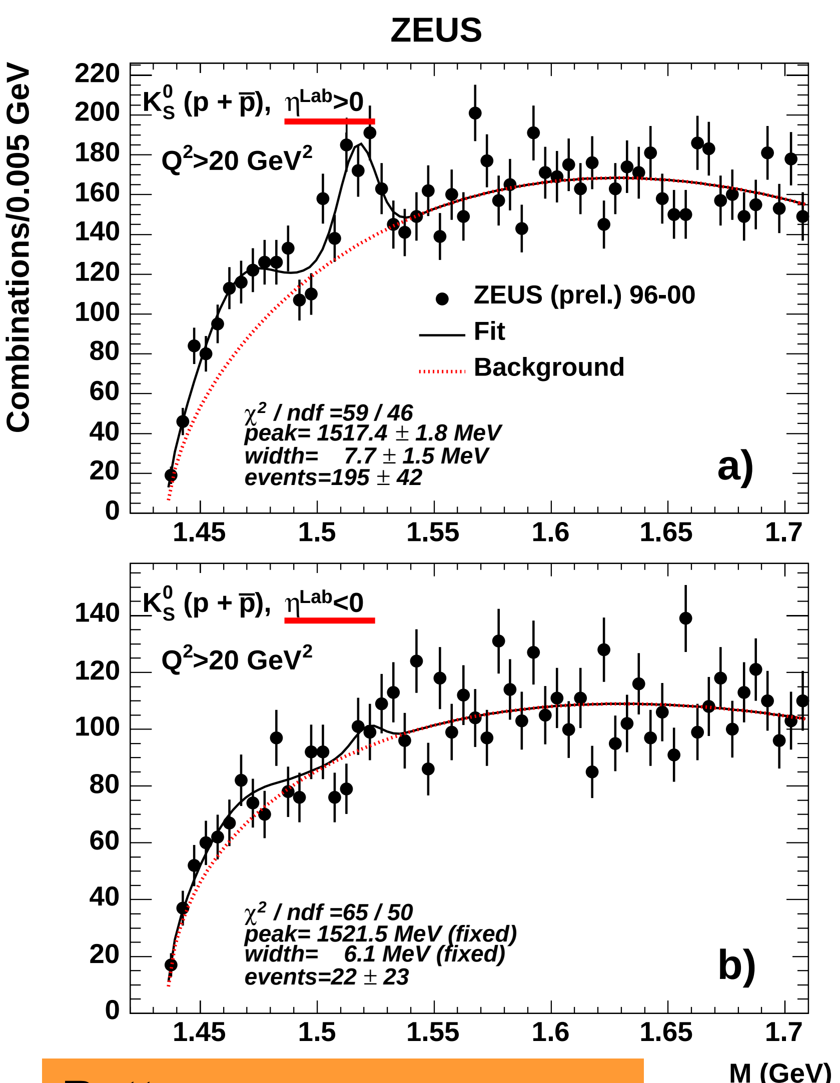
Better seen at higher Q^2

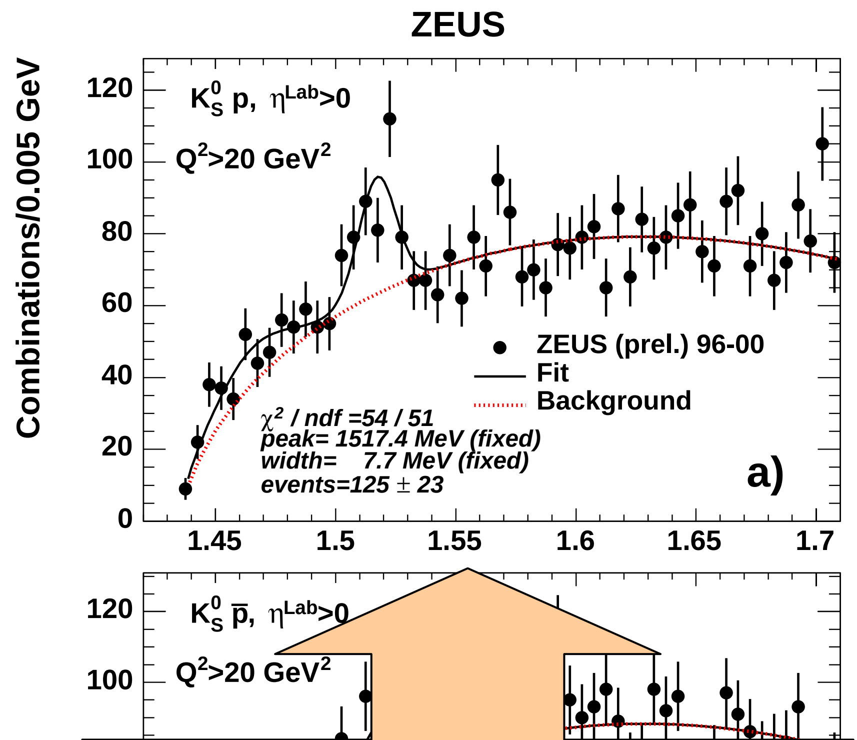
Better seen at low W



Slightly more Θ^+ than $\overline{\Theta}^-$?

suggesting different production mechanism from baryons ?





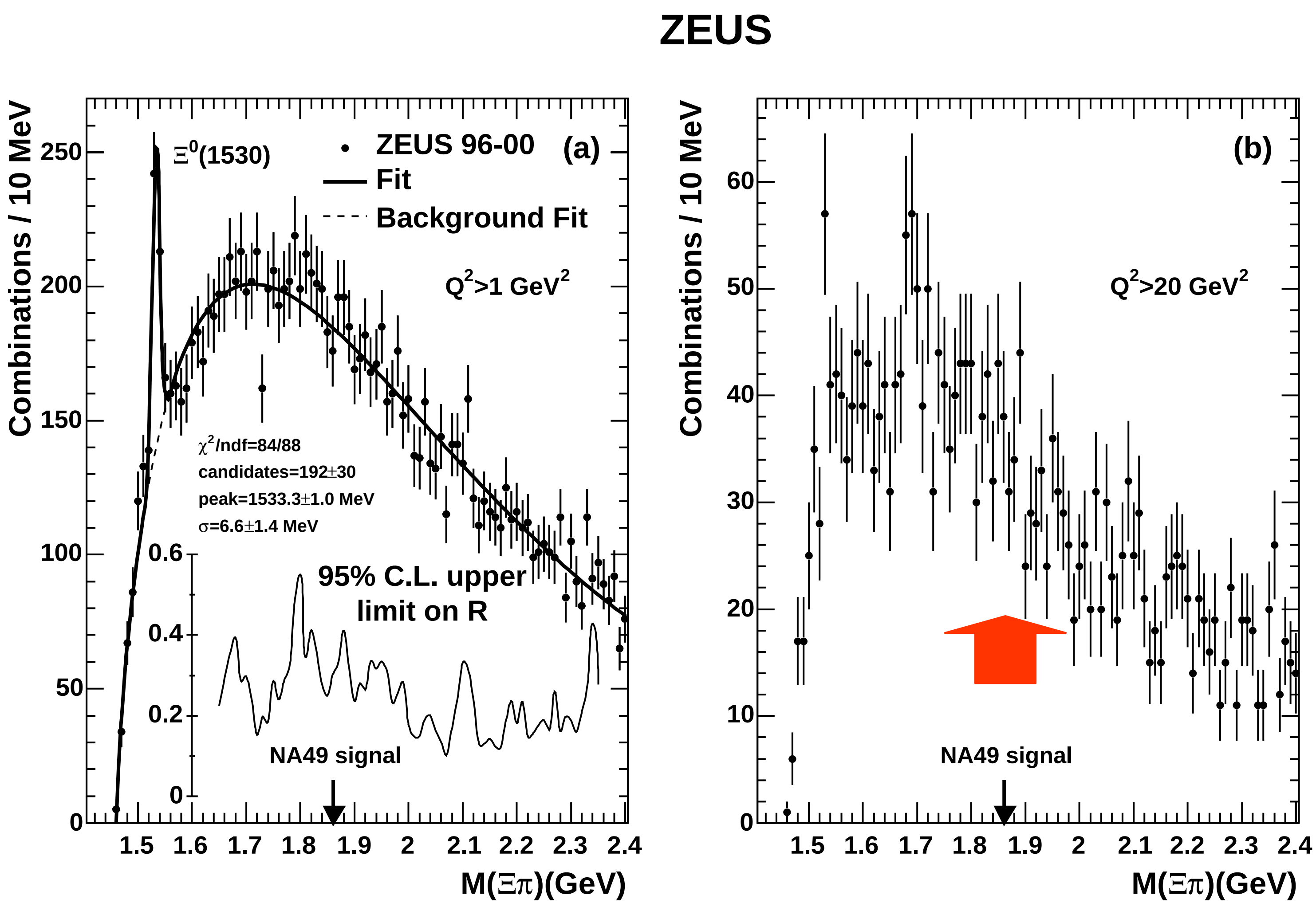
Most significant (5.4σ) plot (High Q^2, forward, K^0p)

Better seen in forward region (in lab)

suggesting different production mechanism from baryons ?

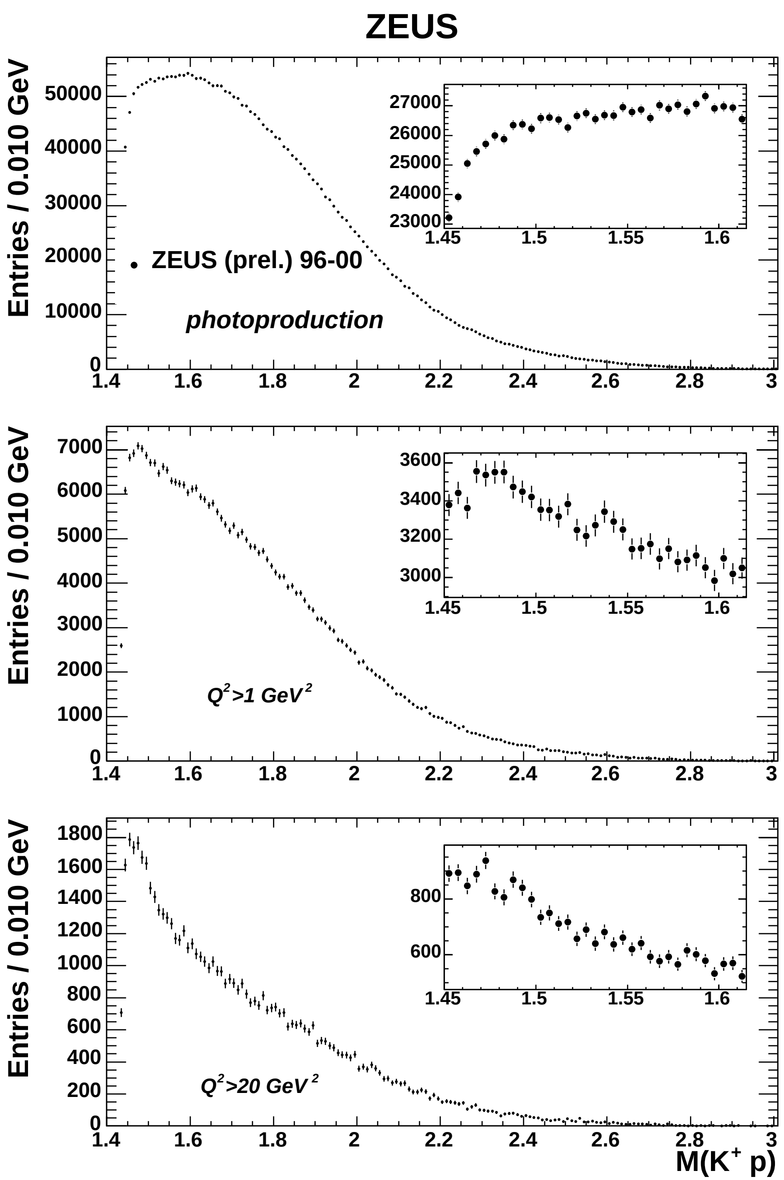
No sign for $\Theta^+ \rightarrow \Lambda\, \pi^+$

Ξπ Pentaquark



No signal around NA49 peak position

Θ^{++} (K$^+$p)



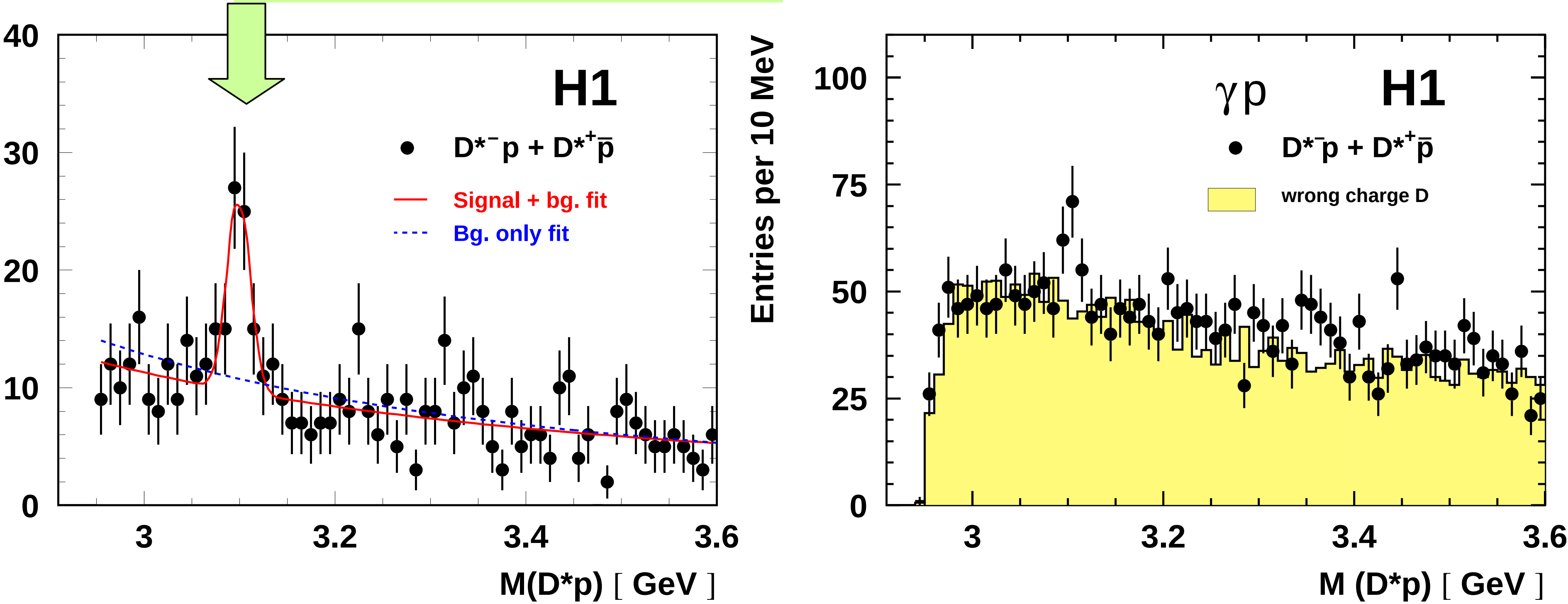
No signal

Θ_c or ($D^{*-}p(3100)$)

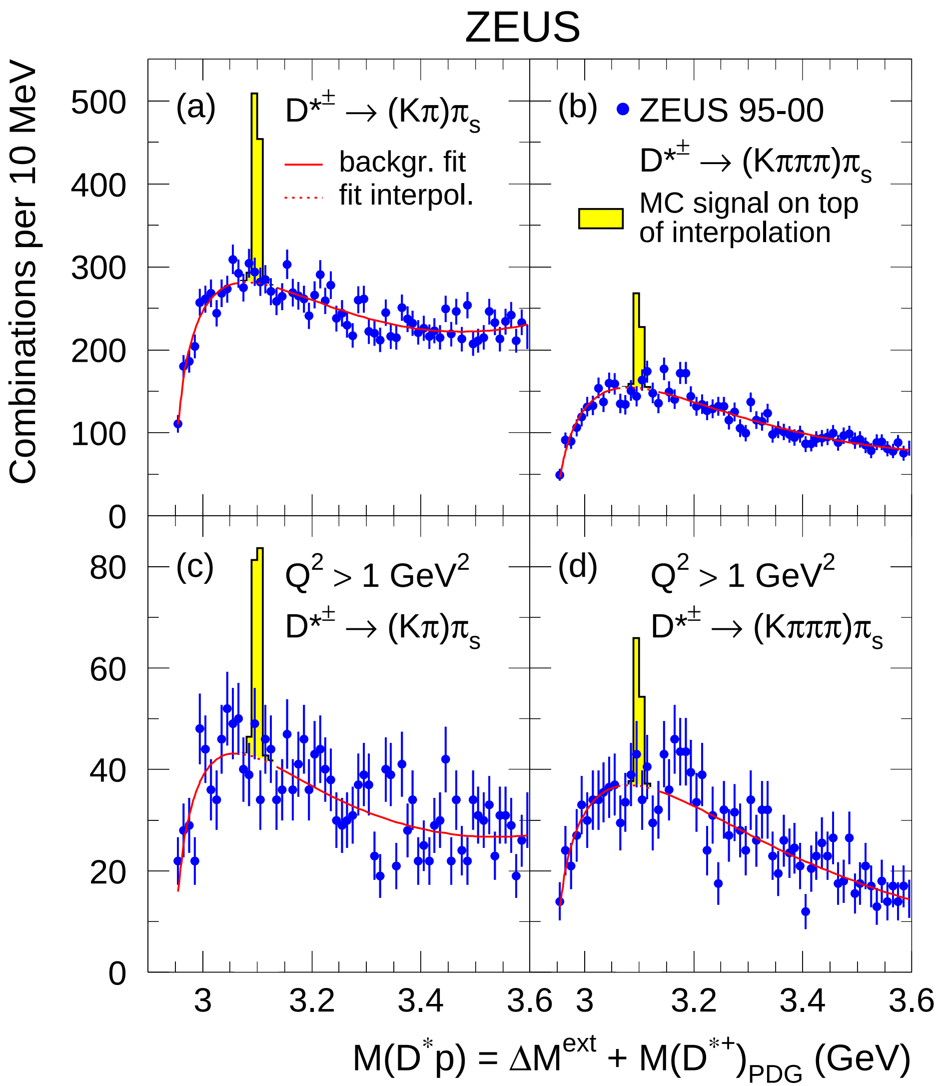
DIS

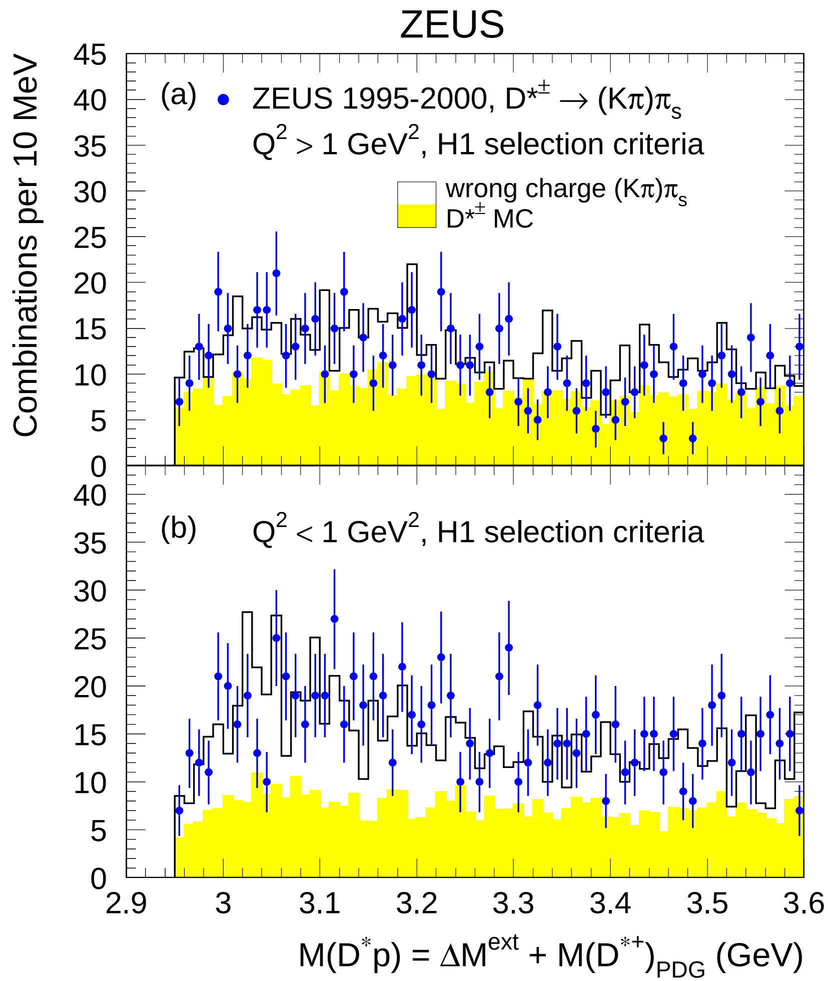
Mass = 3099+-3+-5 MeV
Width = 12 +-3 MeV

Photoproduction



Very clear peak in D*p mass
both in DIS and in photoproduction



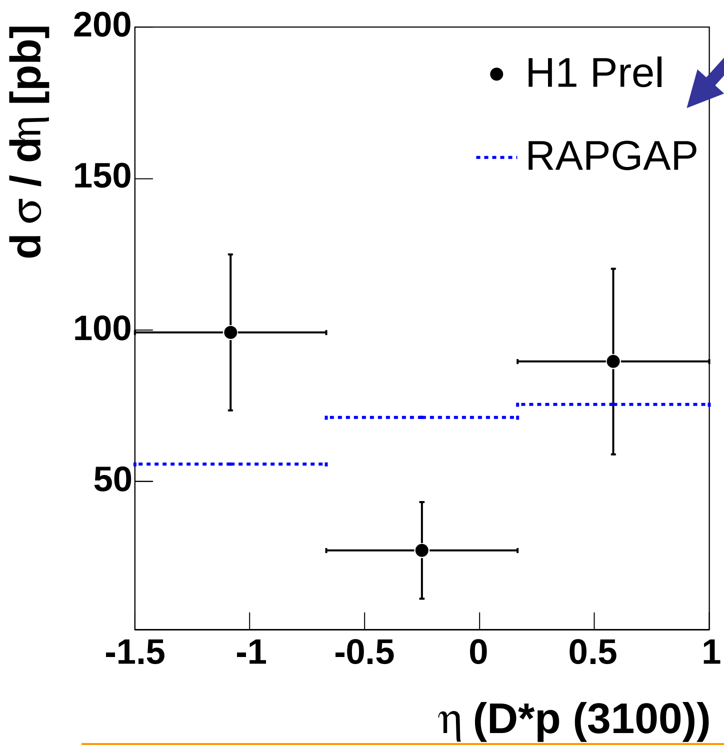


ZEUS published null results.
incompatible to H1's cross section.

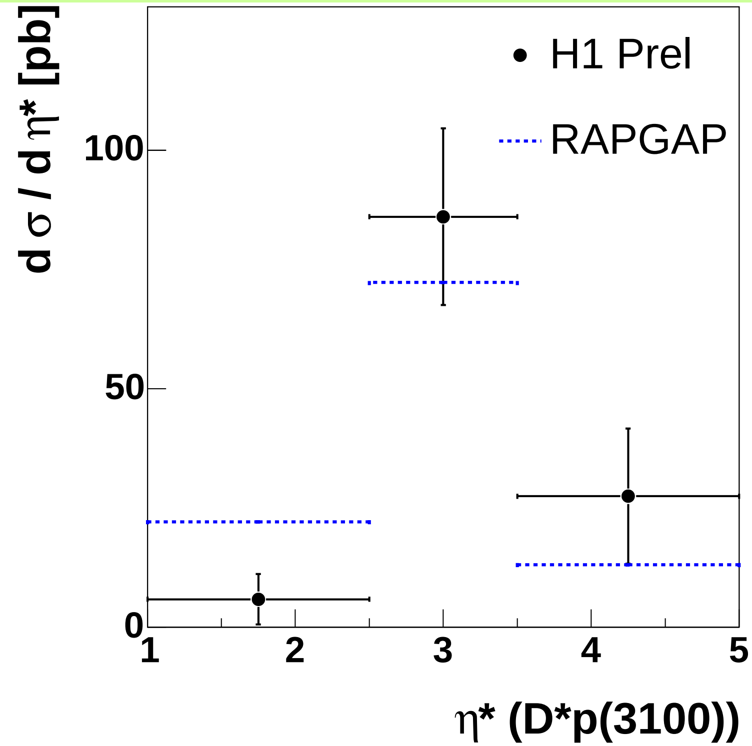
→ need to check HERA-II data

($D^{*-}p(3100)$) properties

A Model assuming D*p is produced similar to D's (D1(2420), D2*(2460))
The isotropic decay is assumed.



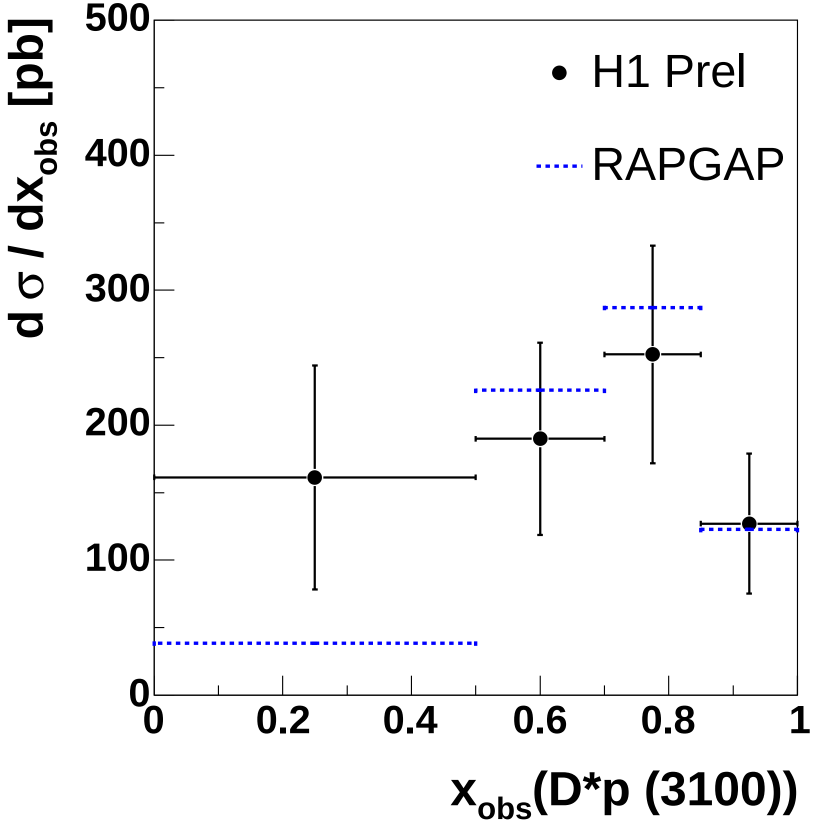
pseudo-rapidity in lab-frame

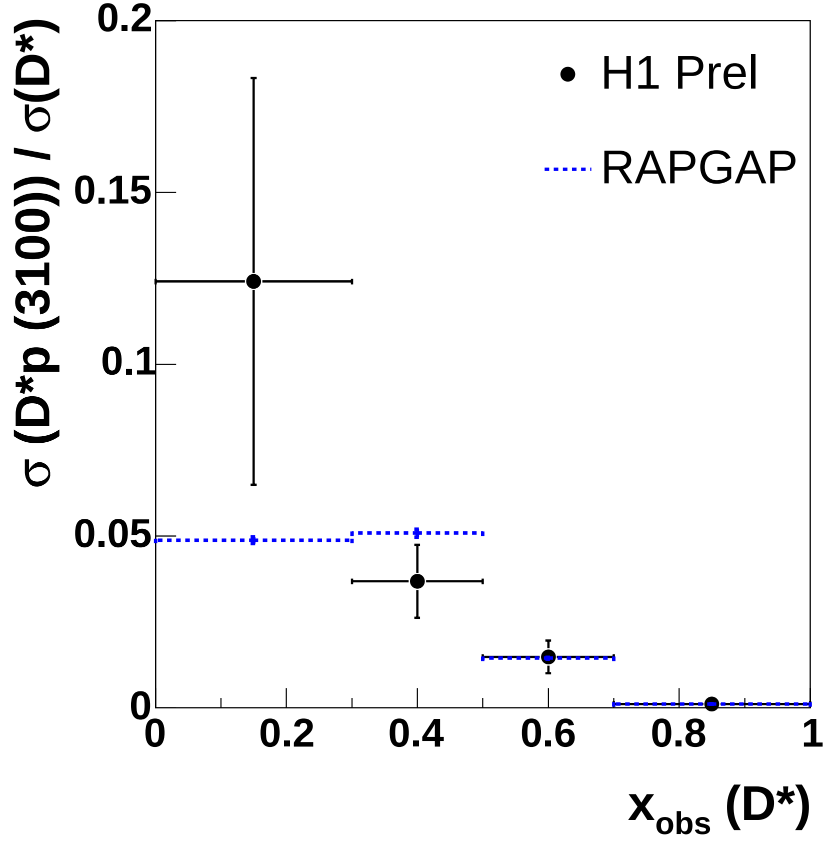


pseudo-rapidity in hadronic-cm-frame

D*p seems to suppressed in the central region.

(D*-p(3100)) properties





D*p(3100) carries a large fraction of charm quark momentum
D* from D*p(3100) has lower momentum

qqqqq summary

• Pentaquark results from H1 and ZEUS show incoherent views.

Θ^+ candidates are seen in ZEUS data and not in H1 data.
Θ_c candidates are seen in H1 data and not in ZEUS data.

•Properties of observed signals are studied. There are several indications that their production mechanism is different from the ordinary baryons.

- Θ^+ : Fwd/Bwd asymmetry, $\Theta/\overline{\Theta}$ asymmetry,
  (associate production with $\Lambda(1520)$: LEPS)
- Θ_c : deficit in the central region.
  Harder fragmentation function.

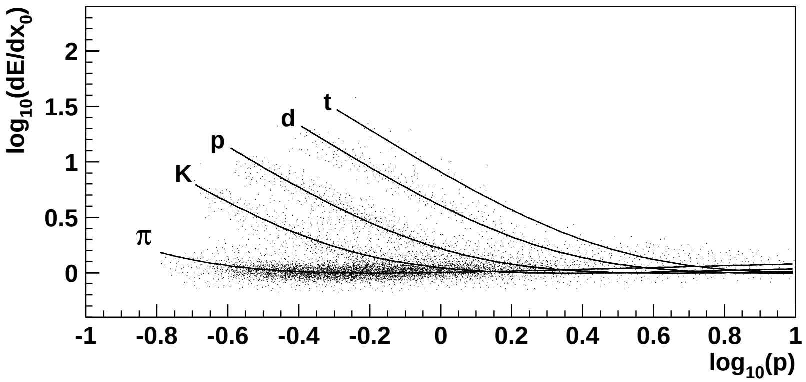
•We definitely need new results from HERA-II to conclude if 5-q system exists.

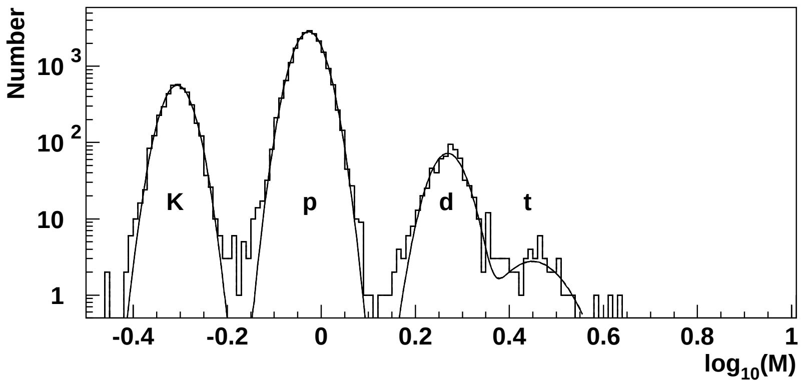
qqqqqq

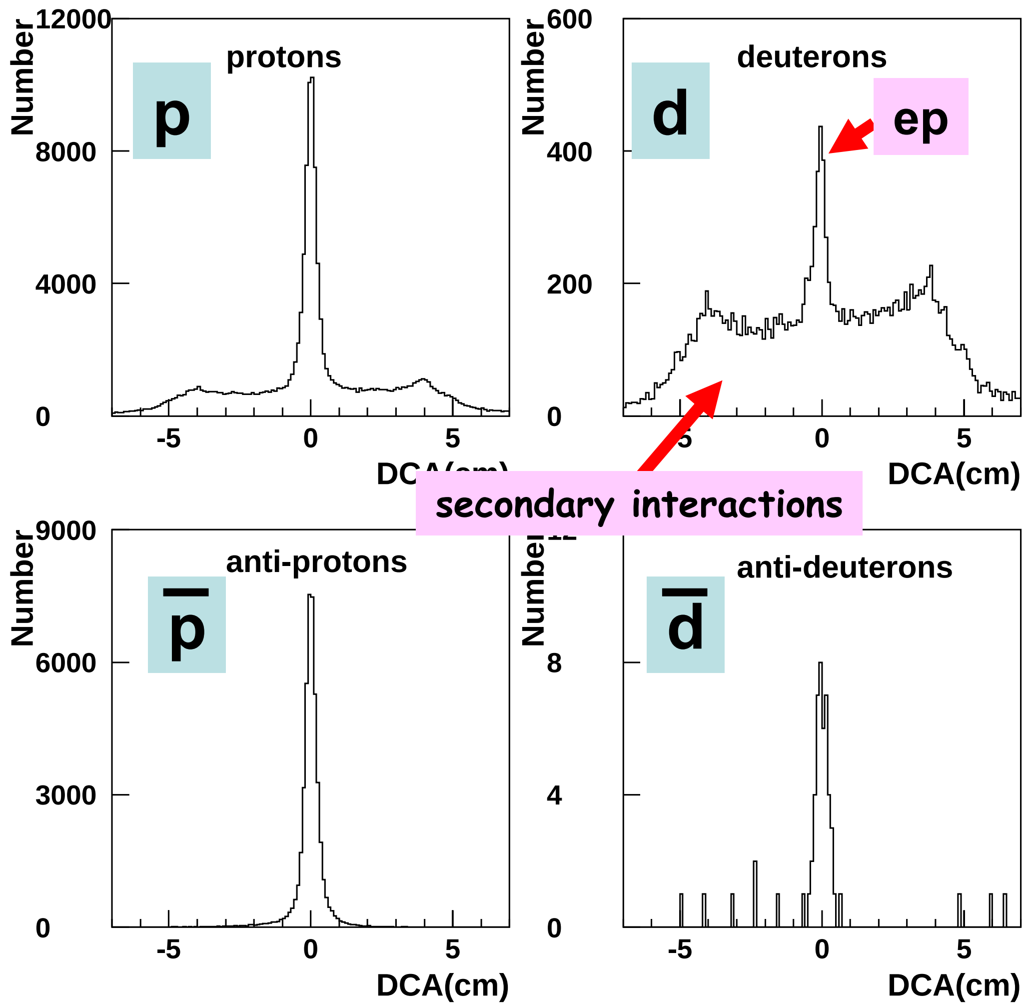
or

qqq qqq

Deuteron

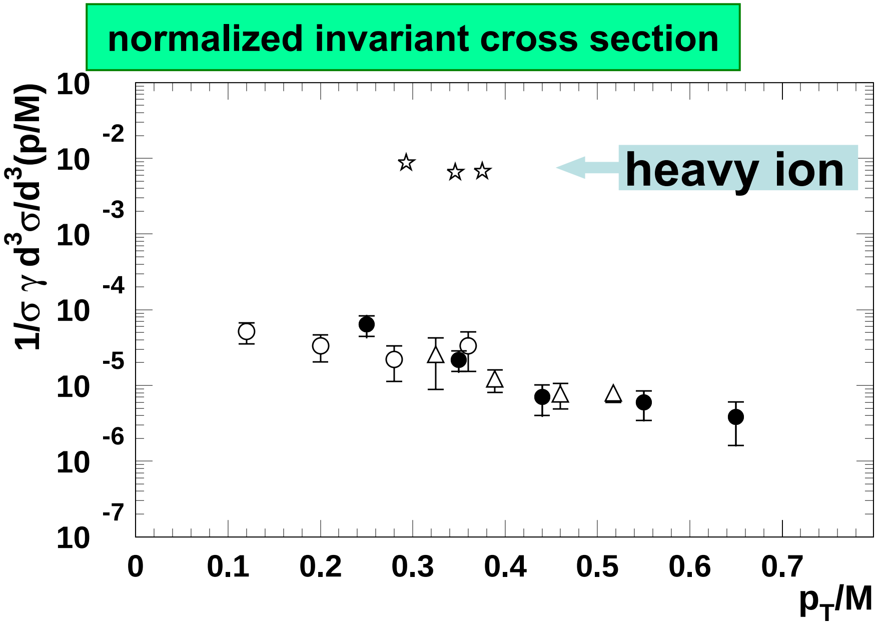




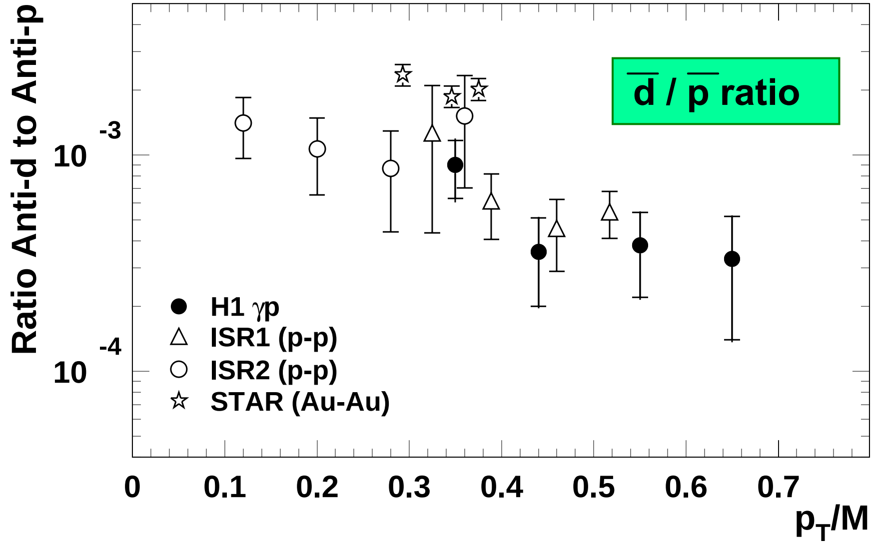


Deuteron band is clearly visible in dEdx in gas chamber.

Many are coming from secondary interactions.
Anti-protons and anti-deuteron are much cleaner



Anti-deuteron yield is similar to pp collision @ISR



$\overline{d}/\overline{p}$ ratio ~ 10^{-3}

Coalescence model

deuteron | proton | neutron

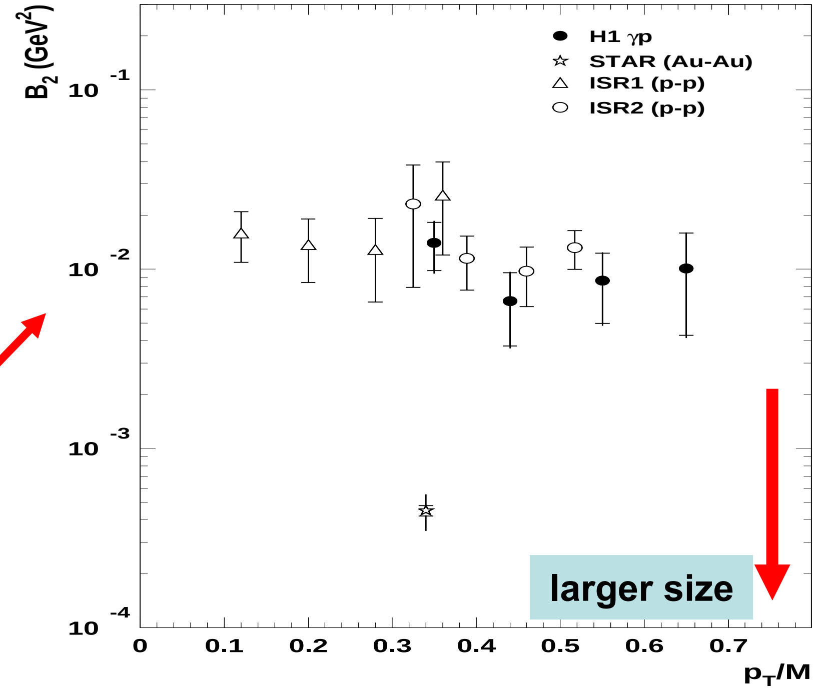
$$\frac{\gamma}{\sigma_0}\left(\frac{d^3\sigma_d}{dp^3}\right)=\left[\frac{3}{4}\right]\left[\frac{4\pi p_0^3}{3}\right]\left[\frac{\gamma}{\sigma_0}\left(\frac{d^3\sigma_p}{dp^3}\right)\right]\left[\frac{\gamma}{\sigma_0}\left(\frac{d^3\sigma_n}{dp^3}\right)\right]$$

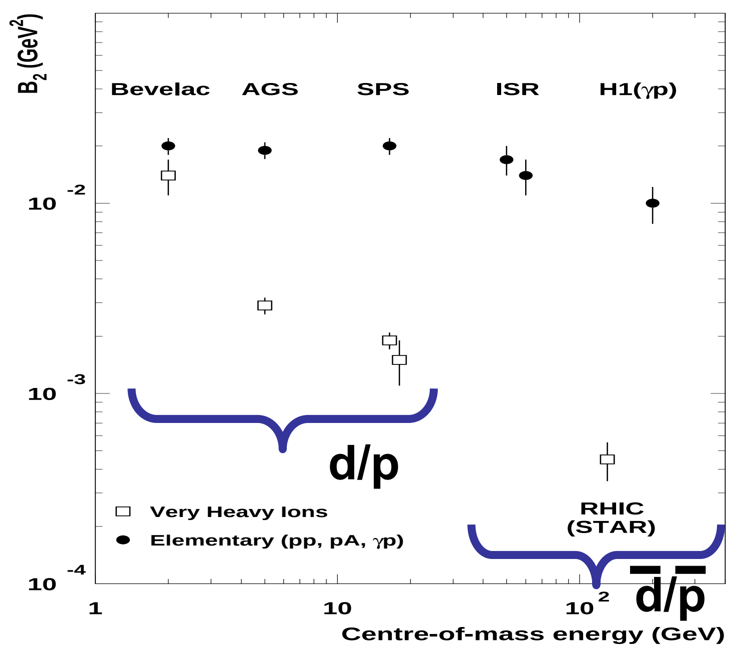
spin factor

p-space volume
where p and n coalesce

$$\frac{\gamma}{\sigma_0}\left(\frac{d^3\sigma_d}{dp^3}\right)=B_2\left[\frac{\gamma}{\sigma_0}\left(\frac{d^3\sigma_p}{dp^3}\right)\right]^2$$

$$m_p B_2 \propto R^{-3}$$





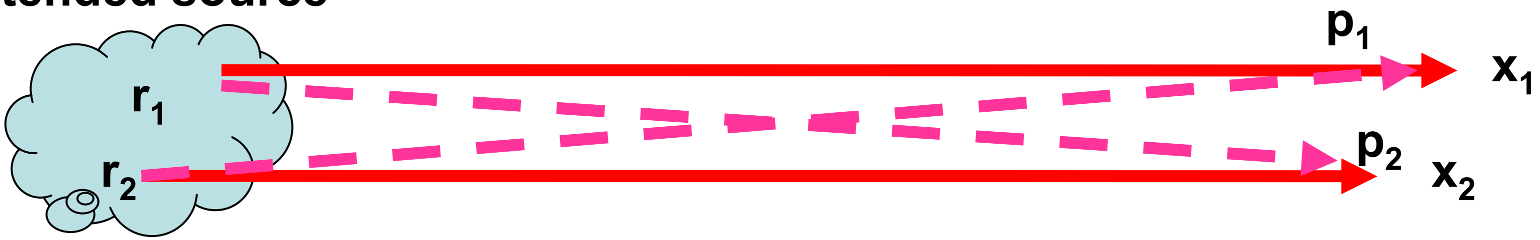
HERA results: consistent to pp, pA reaction.
(Heavy ion collisions shows larger source size)

Bose-Einstein correlation

Or Hanbry-Brown Twiss Effect

:Another tool to measure the interaction volume

Extended source

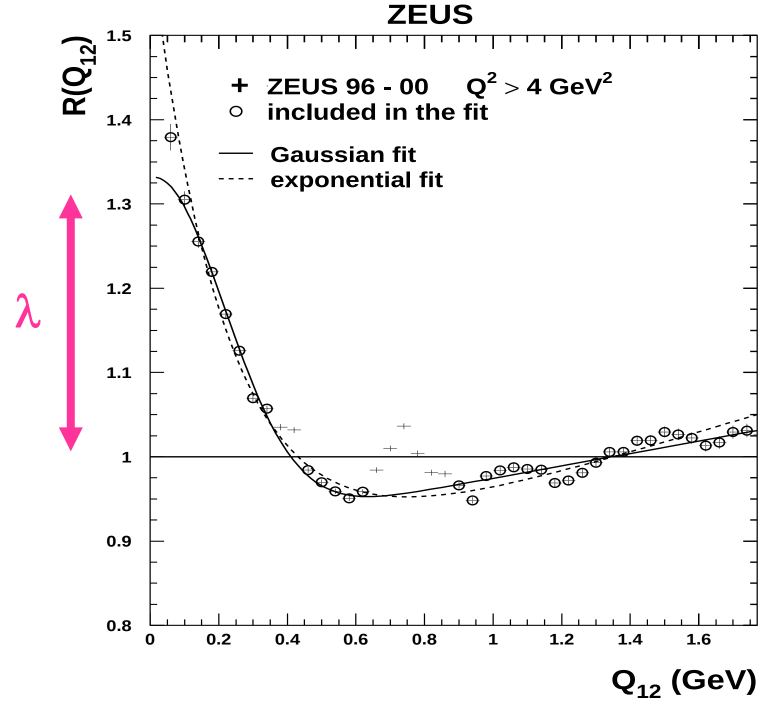


$$\Psi(p_1,p_2) = A_1(p_1)A_1(p_2)\left[e^{ip_1(x_1-r_1)}e^{ip_2(x_2-r_2)} + e^{ip_1(x_1-r_2)}e^{ip_2(x_2-r_1)}\right]$$

$$C(p_1,p_2) = \frac{|A_2(p_1,p_2)|^2}{|A_1(p_1)|^2|A_1(p_2)|^2} = 1 + \lambda\exp(-R^2 Q_{12}{}^2)$$

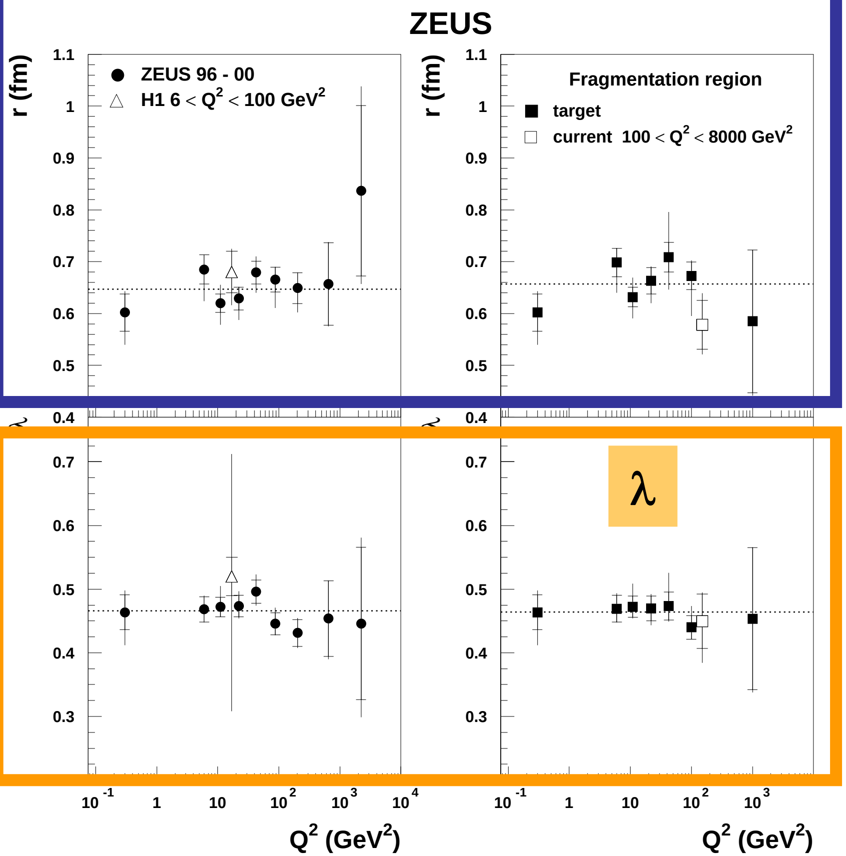
incoherent factor

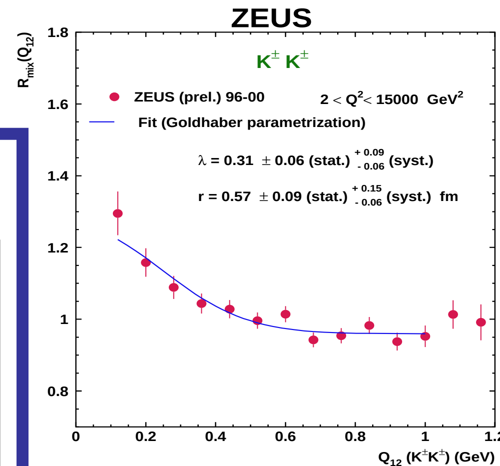
source size

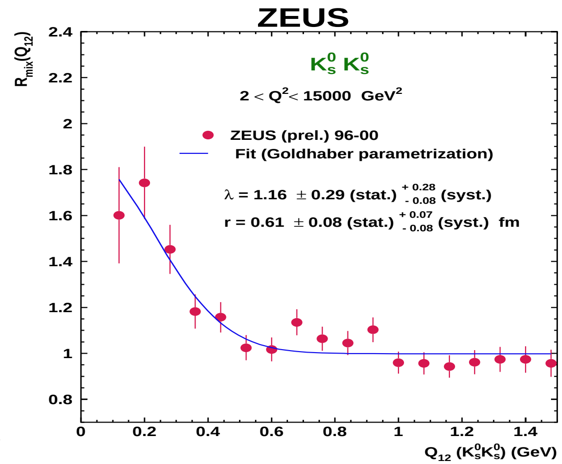


λ~1 if completely incoherent emission

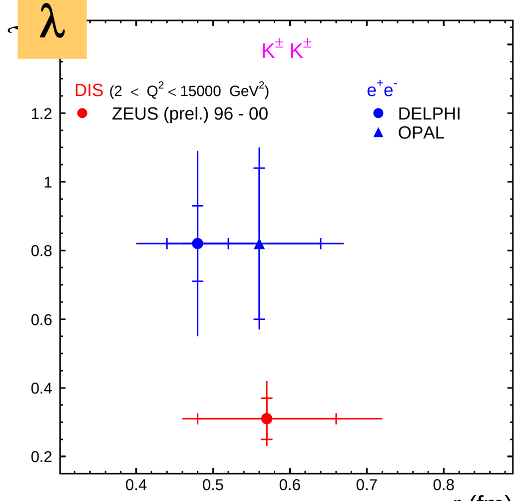
source size

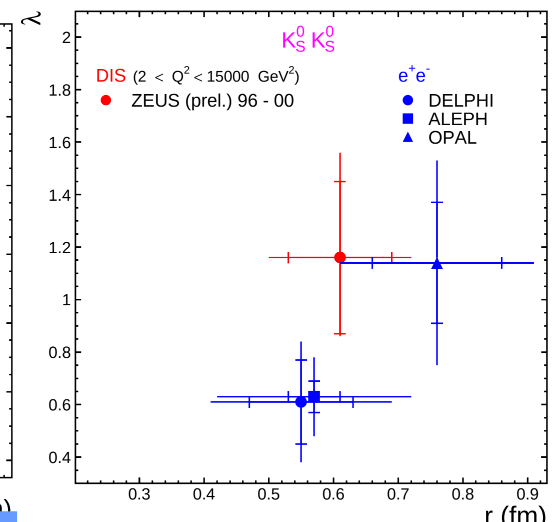






λ





source size

HERA results: ~ 0.6 fm: consistent to other high energy reaction. (Heavy ion collisions shows larger source size)

qqqqqq summary

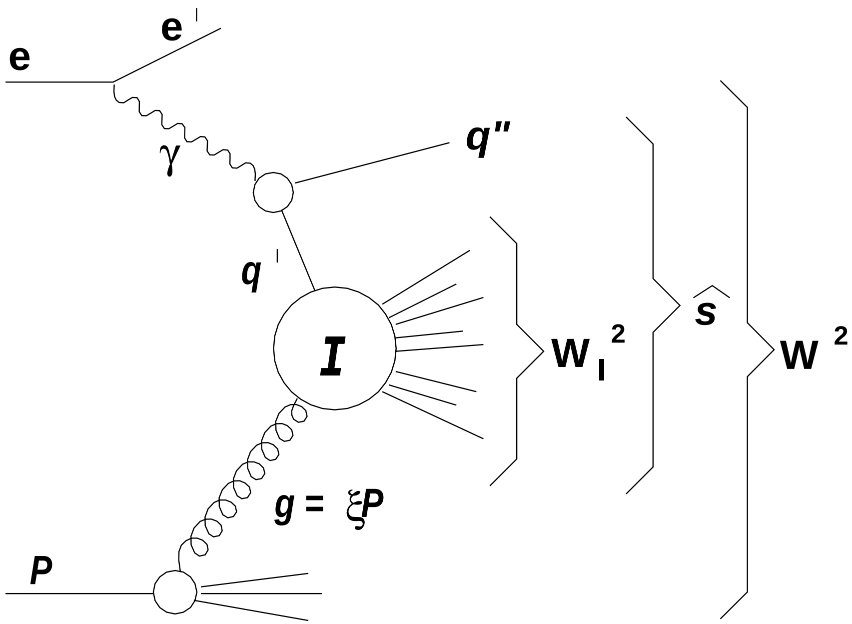
- Anti-deuteron is observed for the first time in γp reactions.
- Anti-d multiplicity, d/p ratio is similar to p-p, p-A reactions. In heavy ion collisions, the multiplicity is much higher (O(1000)), with similar d/p ratio.
  - In the coalescence model, this results the significantly larger source size in Heavy ion reactions than in ep, pp, pA.
  - The source size seen from two pion interferometry (B.E. correlation) shows that ep reaction and the other ee, pp are similar.

- Applying statistical models, "source size" of ep collisions are studied. From B.E. correlation, source size seems to be independent to the event kinematics (Q^2, W...).

  Do deuterons confirm this? → HERA-II?
- Any models beyond statistical approach?

$$q_R \bar{q}_R q_R \bar{q}_R q_R \bar{q}_R q_R q_R \ldots$$

Instanton



$$q + g \xrightarrow{I} \sum_{n_f} (q_R + \bar{q}_R) + ng$$

$$q + g \xrightarrow{\bar{I}} \sum_{n_f} (q_L + \bar{q}_L) + ng$$

In QCD, certain processes violate the conservation of chirality. – Instantons.

--> Non-perturbative fluctuation of the gluon field. Tunnelling between 2 vacuum states.

Ringwald and Schrempp pointed out that instanton-induced events can be seen in DIS. The cross section is calculable in a certain kinematical region (defined by q' and g--> instanton size (ρ)) . σ~ 100 pb.

Events are expected to have distinct signature.

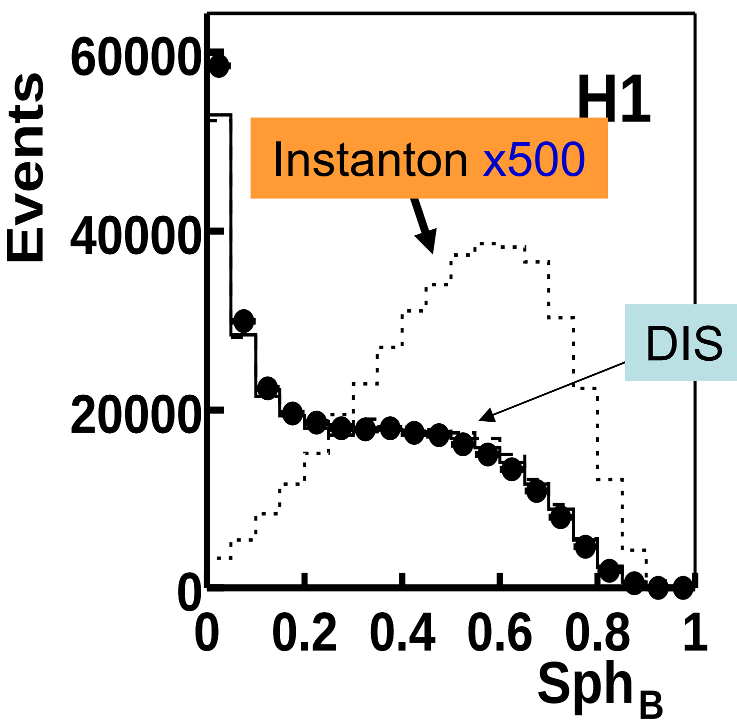
- Many quark and gluons --> fireball like
- Flavour democratic --> many K

Instanton

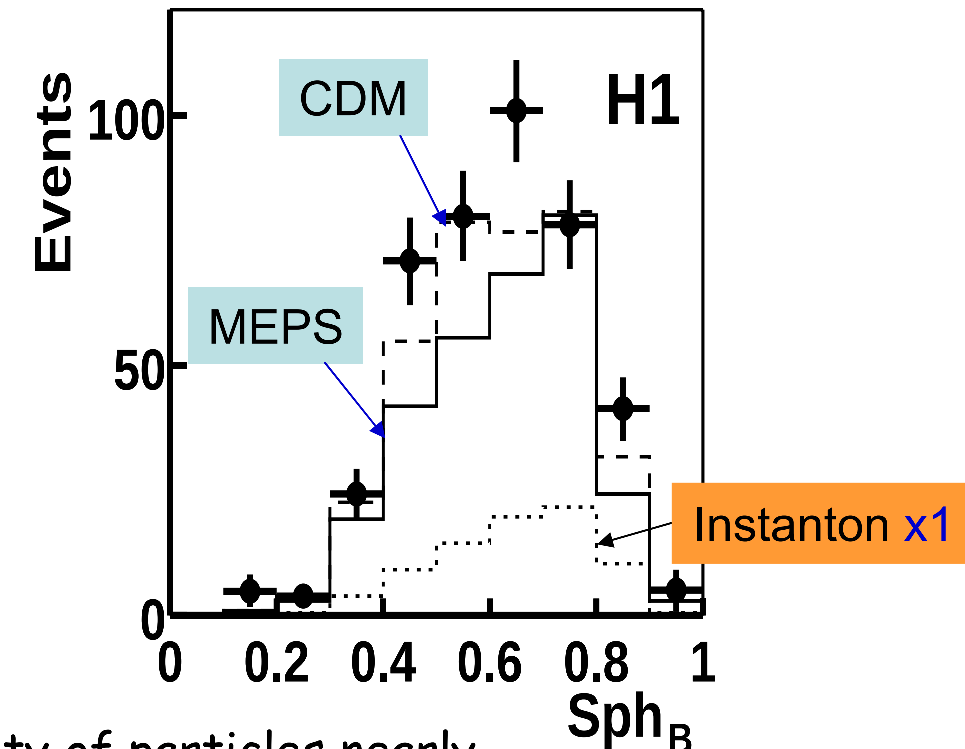
Instanton events have different particle emission patterns from the normal DIS. But the expected production rate is not so large

After the selection cut to enhance the instanton-like sample, the difference in the two normal-DIS MC's predictions are still large

One example

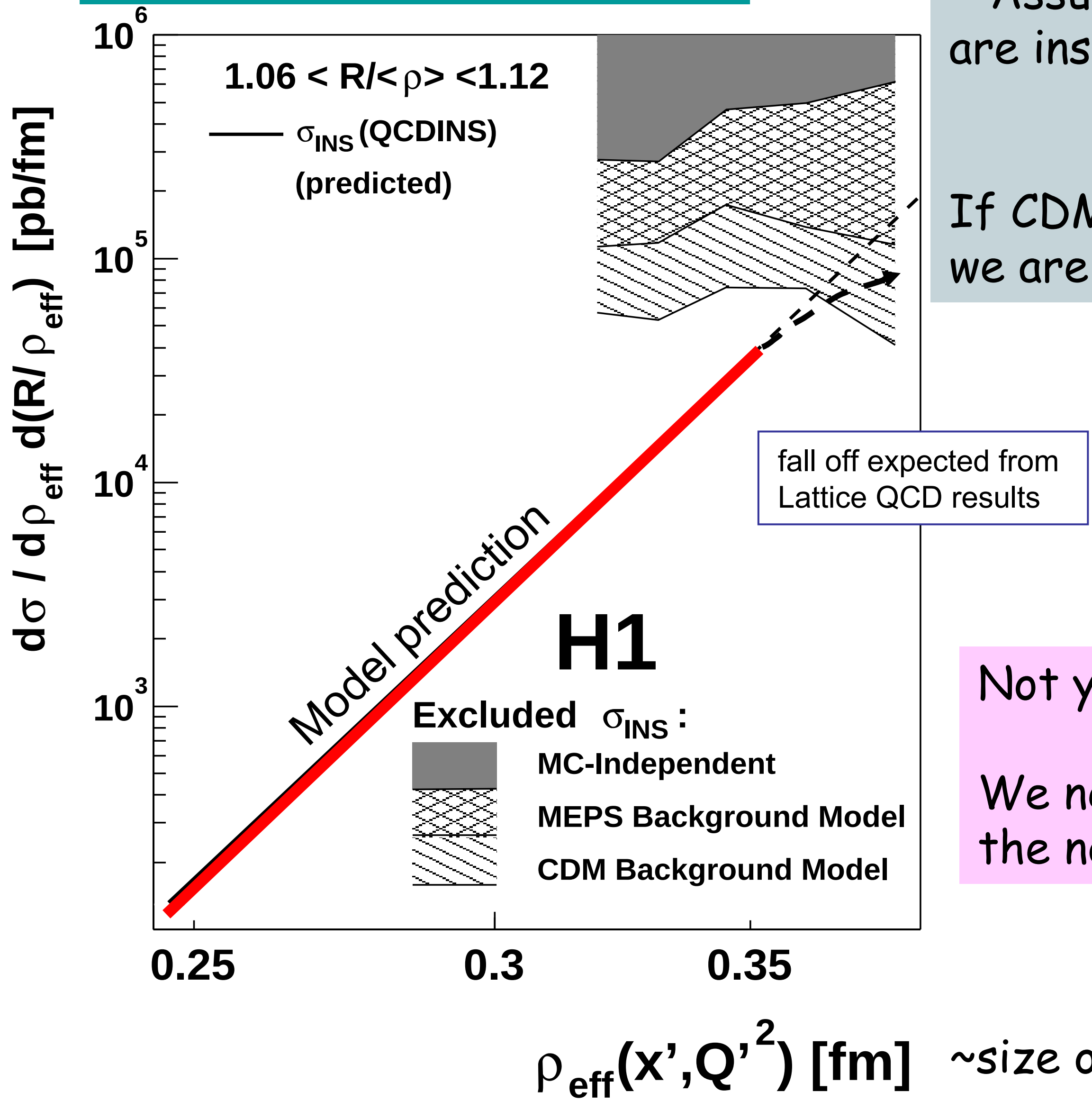


After Enrichment cuts.



Sphericity of particles nearly I-rest frame

Instanton



~size of instanton

MC-Independent:
Assuming all remaining events are instanton-induced:
(very conservative)

If CDM is the "correct MC" for DIS we are closer to set limit.

ZEUS used the higher Q^2-region for the similar search.

Not yet give a stringent limit.

We need more understanding for the normal DIS process.

Summary

• A lot of measurements of mesons and baryon productions have been performed at HERA. Trying to enhance (exotic) signals, various kinematical cuts (Q2, W ...) are used. This is one of the advantages of ep collisions.

• Pentaquark results from H1 and ZEUS show incoherent views on the subjects. We definitely need new results from HERA-II to conclude if 5-q system exists.

•Anti-deuterons are for the first time observed in γp collisions. In the frame work for the coalescence model, the size of the reaction source in ep are similar to the other “fundamental” process (ee, pp).

•Search for genuine QCD effect (such as Instanton-induced process) was performed in HERA-I. We need to understand the normal DIS better. At the same time we need to find the better observables.

•All results shown in this talks are with HERA-I data. We expect further progress by using high statistical HERA-II data, since many results are still statistically limited, after various selections.