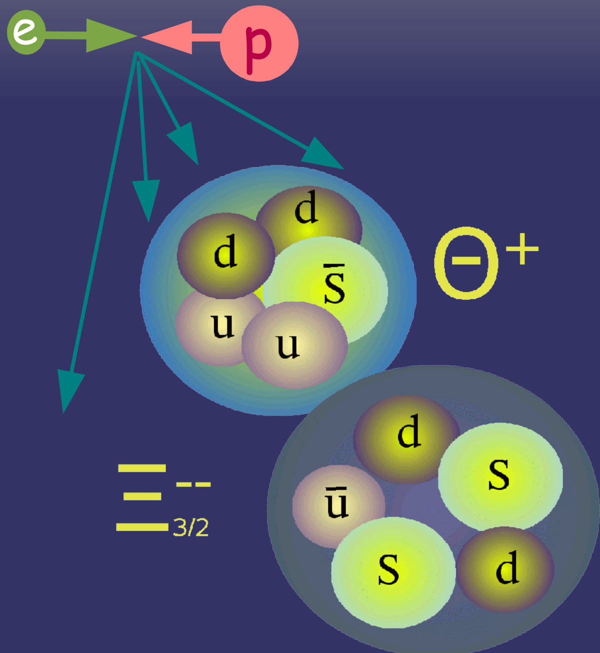
Search for narrow baryonic states in DIS events at HERA



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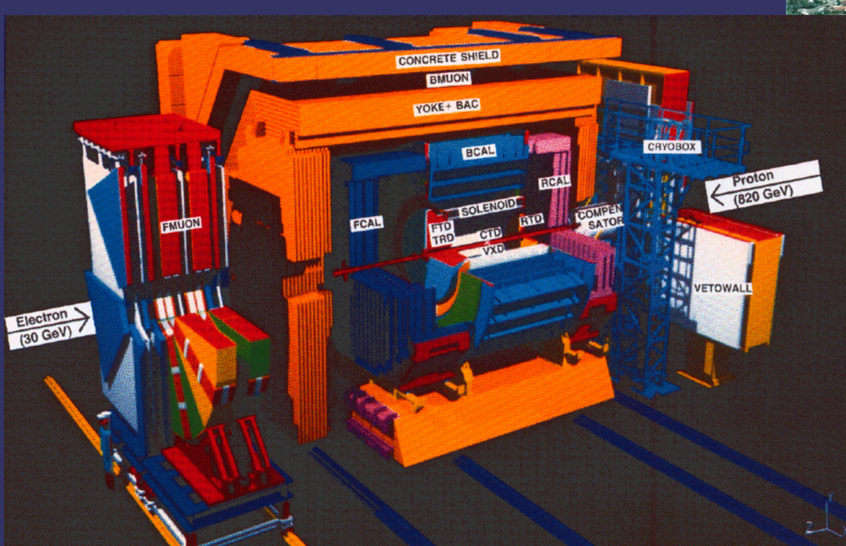
ZEUS Collaboration

DIS04, High Tatras, Slovakia,
April 14-18, 2004



$$\sqrt{s} = 300 - 318\, GeV$$

Introduction-I

Constituent Quark Model (CQM) describes:

- Mesons as bound state of a quark and an antiquark: $q\,\bar{q}$
- Baryons as bound state of three quarks: $q\,q\,q$ +absence of baryons with strangeness S=+1

CQM does not predict more complicated states, but can accommodate them:

Examples:
- excitations of QCD vacuum (glueballs): $g\,g$
- states with an excited gluon (hybrids): $q\,q\,g$, $q\,q\,q\,g$
- multiquark states: $q\,q\,\bar{q}\,\bar{q}$, $q\,q\,q\,q\,\bar{q}$ etc.. (could have S=+1)

☞ Many models available

Chiral Quark Soliton model (D.Diakonov, V.Petrov and M. Polyakov):

- Baryons: rotational states of the soliton nucleon in spin and isospin space
- Predicted: spin 1/2, isospin 0, strangeness S=+1, mass (~1530 MeV), width (<15 MeV)
  - very narrow – CQM cannot explain this, the soliton model can!
- lightest baryon has quark structure $u\,u\,d\,d\,\bar{s}$

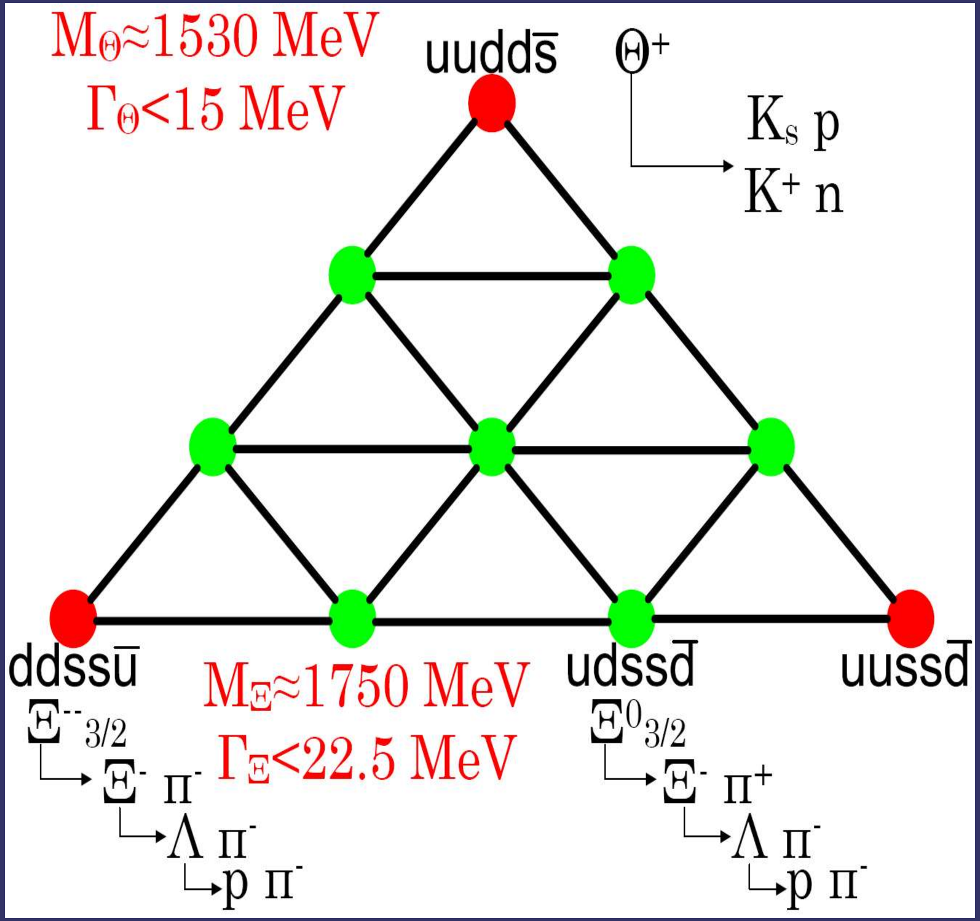
Introduction-II

- A number of low-energy fixed-target experiments observed a narrow baryonic resonance at ~ 1530 MeV with positive strangeness ($K^+ n$ decays)
- Consistent with the pentaquark predictions $uudd\bar{s}$ with $\Gamma<15$ MeV
- Decay mode $K^0 p$ also possible:
  - observations by DIANA, HERMES, SVD, COSY-TOF experiments

Other possible candidates:

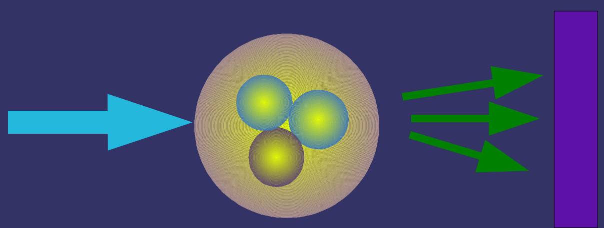
- $\Xi\pi$ channel (NA49): $\Xi^{--}_{3/2}$ and $\Xi^{0}_{3/2}$
- consistent with: $ddss\bar{u}$
  $udss\bar{d}$

If all these measurements will be confirmed and quantum numbers will be determined, this would establish $\overline{10}_f$ →

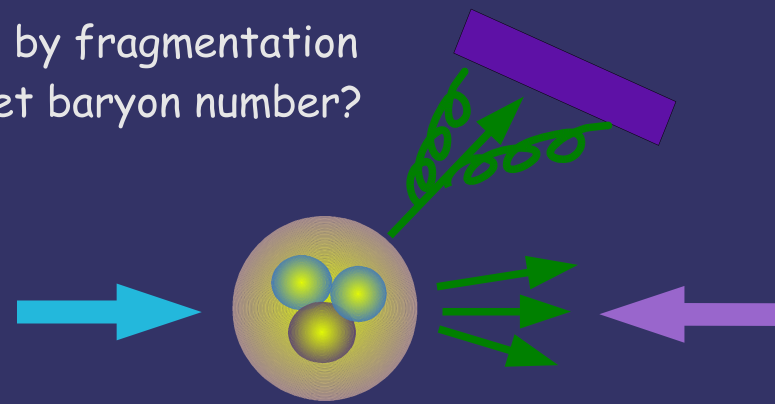


$K_s^0 p$ decays in DIS

- Unlike fixed-target experiments, higher-energy colliding experiments have little sensitivity to the proton remnant:
  - Look at central rapidity regions dominated by fragmentation
  - Can pentaquarks be created without the net baryon number?



fixed-target experiments

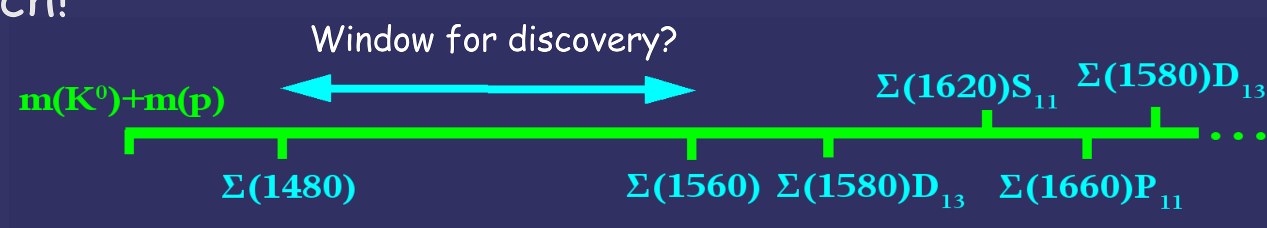


colliding experiments

- PDG reports Σ bumps (unestablished resonances) for this decay channel

  $\longrightarrow$ complicates the search!

Invariant mass of $K^0{}_s p$ channel:



Note from PDG:
- o evidence of existence of Σ bumps is only fair or poor (* or ** in PDG)
- o too low in mass to be accommodated in most quark models
- o never been seen in HEP experiments

DIS kinematics

- **s:** e-p c.m. energy

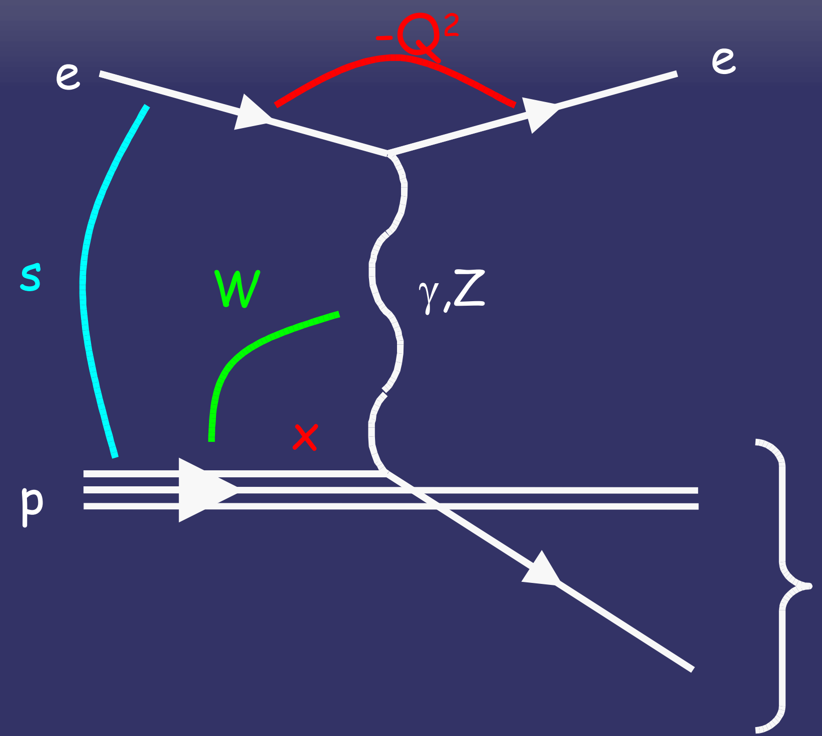
  $\sqrt{s}$ = 300 – 318 GeV

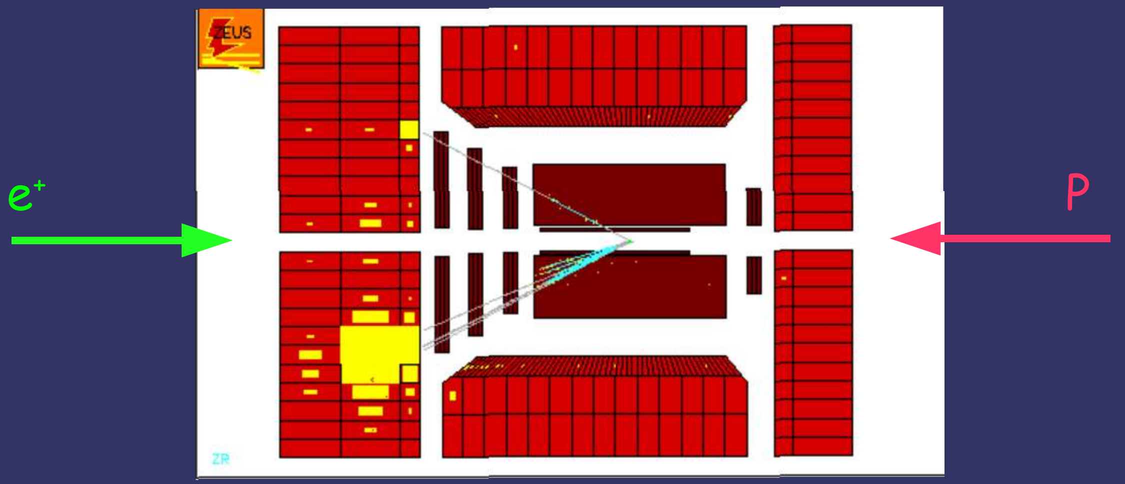
- $Q^2 = -q^2$: 4-momentum transfer squared

- x: fraction of proton momentum carried by quark

- y: inelasticity parameter

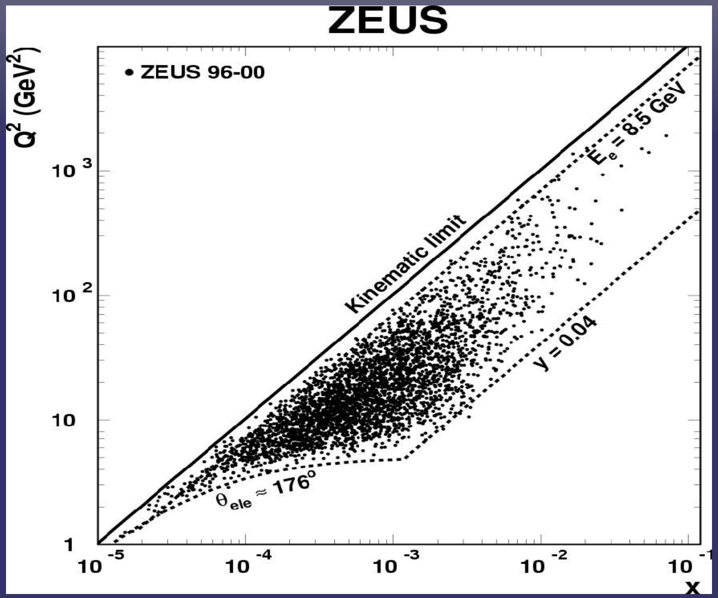
- W: γ -p c.m. energy





Event selection

- 121 pb^{-1} , HERA-I
- e^+p, e^-p collisions
- CM energy of 300-318 GeV;
- $Q^2 > 1\ GeV^2$.



K^0_S selection

- CTD tracks, $p_T > 150$ MeV, $-1.75 < \eta < 1.75$;
- K^0_S reconstructed from secondary-vertex tracks;
- Photon conversions removed: $M(e^+e^-) < 50$ MeV;
- Λ's removed $M(\pi p) < 1121$ MeV;
- $p_T(K^0) > 300$ MeV; $|\eta(K^0)| < 1.5$.

Resolution for Kp masses: ~ 2.0 ±0.5 MeV

MC simulation + consistent with measurements for K^* and Λ_c

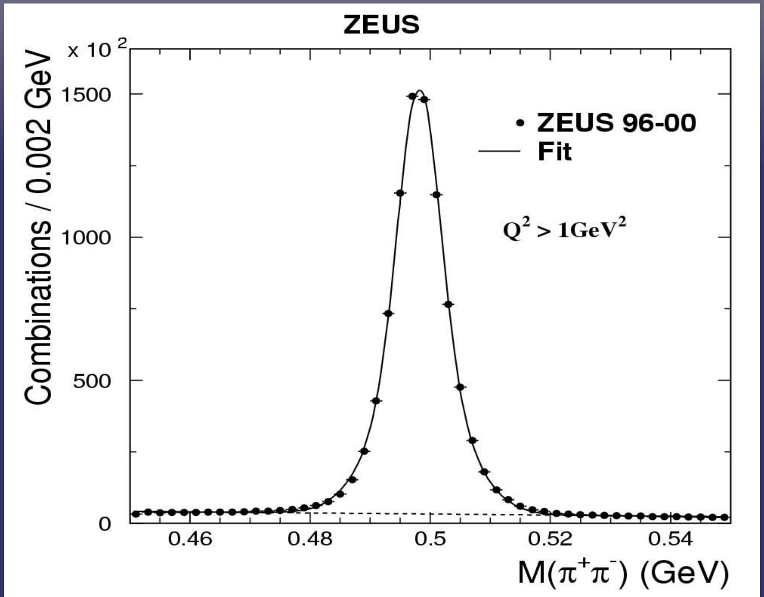
K^0_S and (anti)proton candidates

Fit: Double Gaussian + linear background

~870000 candidates

Background <6 %

Peak:498.12 ± 0.01 (stat) MeV



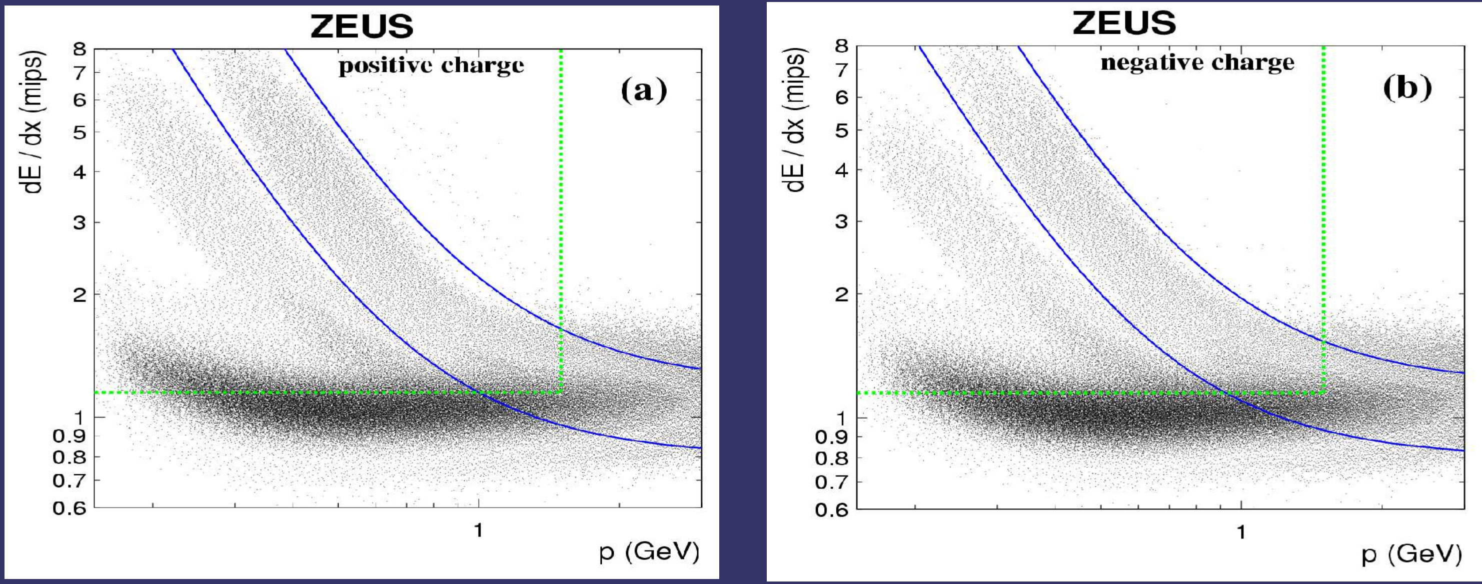
Proton(antiproton) candidates

1) primary tracks

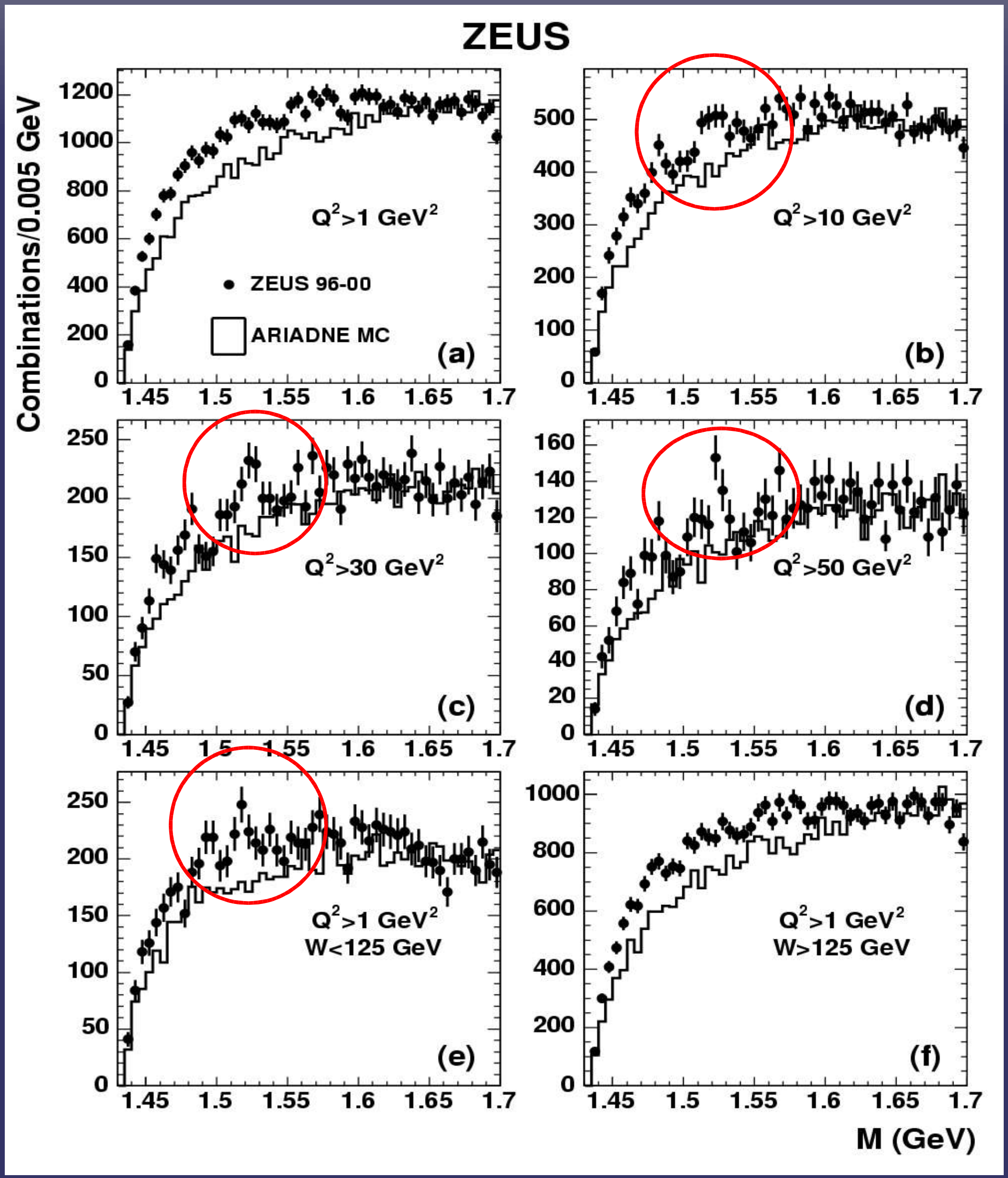
2) f< dE/dX <F

3) dE/dX>1.15 mips

4) p<1.5 GeV

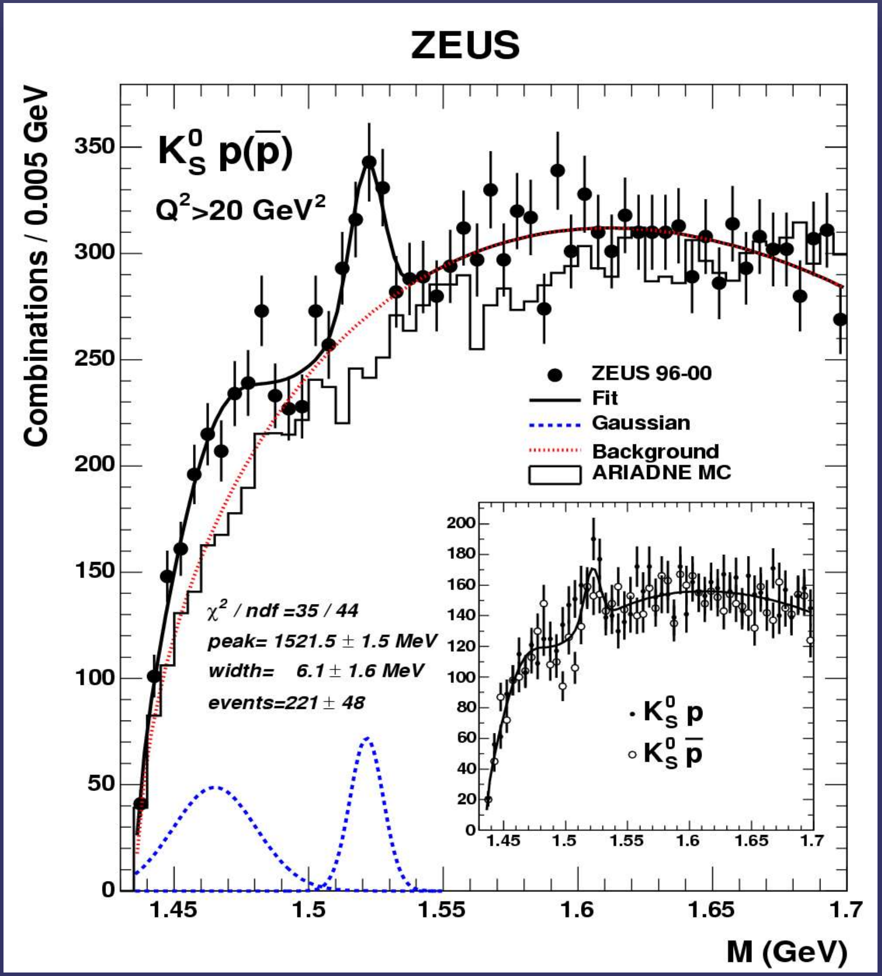


Results: K^0_s p decays



- Structures near 1522 MeV and below
  - increase with Q^2
  - decrease with W

Results: K^0_S p decays: $Q^2 > 20$ GeV^2



Fitting function:

F(M)=2 Gaussians +P1$(M-m)^{P2}$ (1+P3(M-m))

where $m=m_K+m_p$ and

$P_{1,2,3}$ – free parameters

- Peak:

  1521±1.5(stat.)$^{+2.8}_{-1.7}$(syst.) MeV

- Gaussian width:

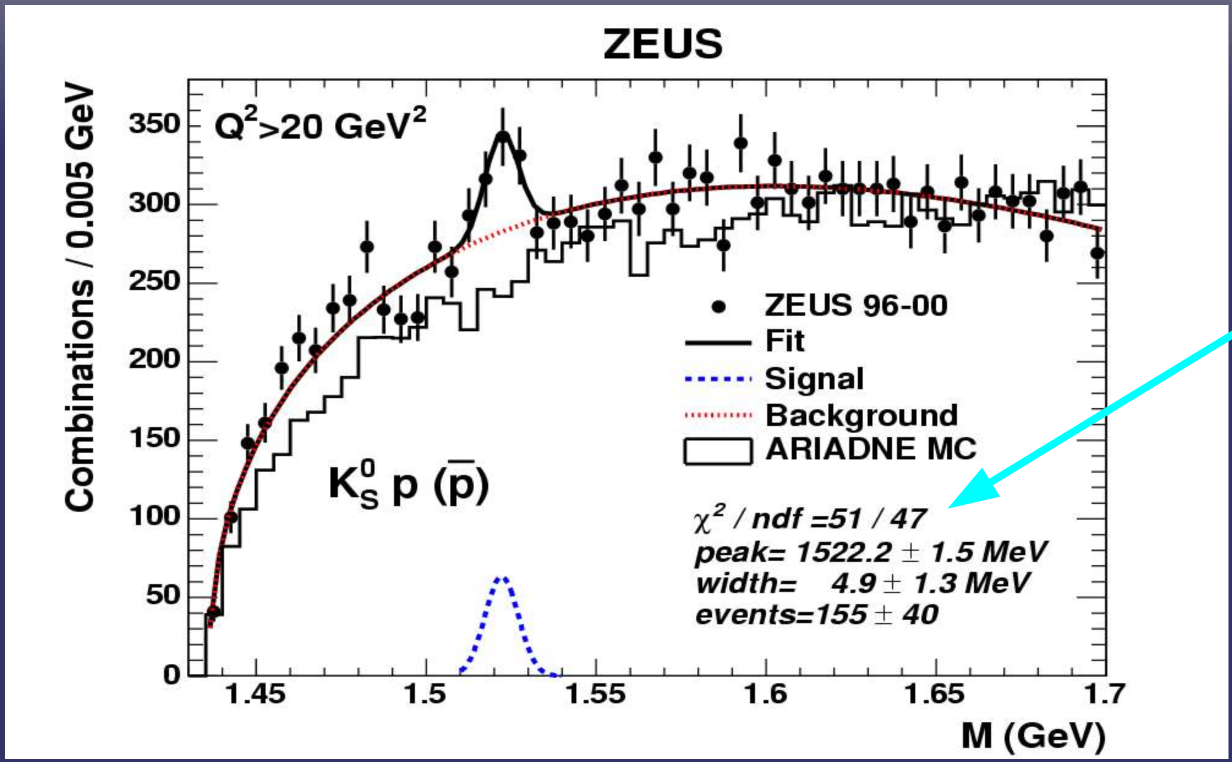
  6.1±1.6(stat.)$^{+2}_{-1.4}$(syst.) MeV

- 221 ± 48 events (4.6σ)

- K^0_S antiproton: 96±34 candidates

  antipentaquarks?

Results: K^0_s p decays



Conservative fit:
Gaussian + threshold

Fit still acceptable, but
χ^2/point=1.4 (<1550 MeV)

MC experiment to estimate significance (for mass range 1500-1560 MeV):

Pr=6×10^{-5} -> similar signal from fluctuations of (threshold) background

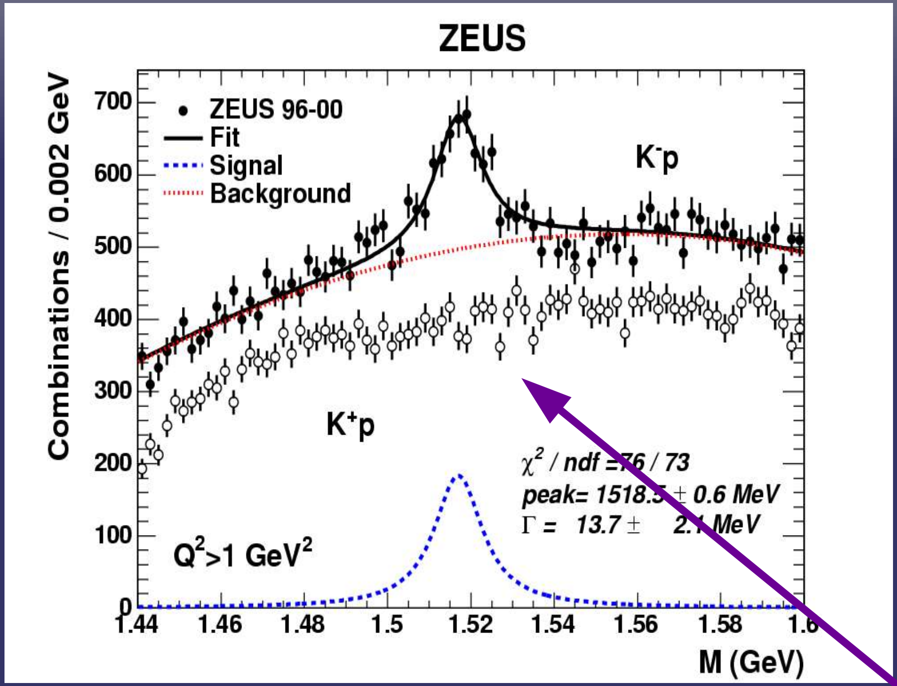
Pr=6×10^{-6} -> threshold + additional Gaussian to describe 1480 MeV region

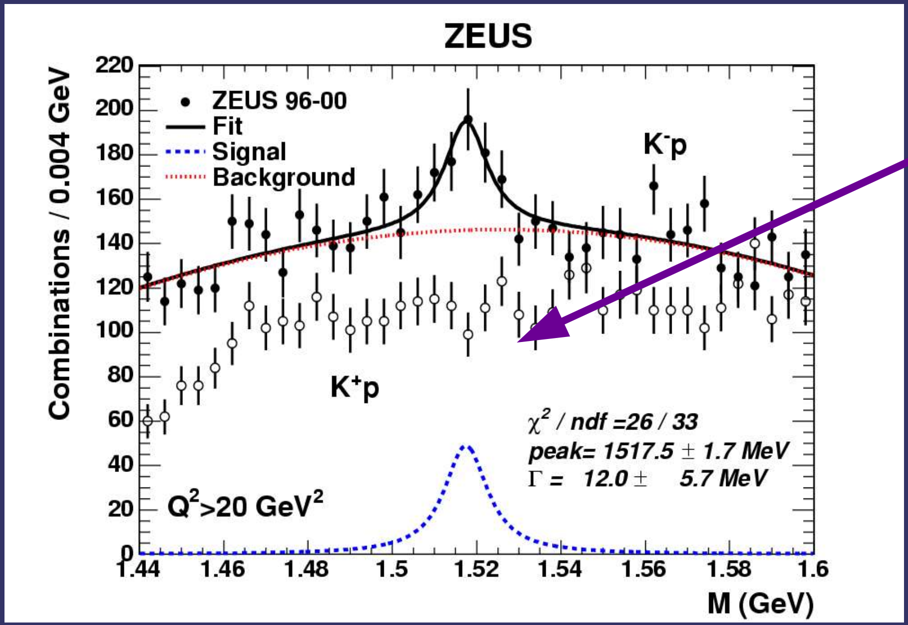
What about the natural width?

- ✔ 8±4(stat.) MeV - from Breit-Wigner fit convoluted with 2 MeV Gaussian resolution
- ✔ systematics is difficult to estimate

→ too narrow, not enough statistics, difficult background

Results: K^+p decays





If Θ^+ is NK bound state, isospins 0 and 1 are both possible

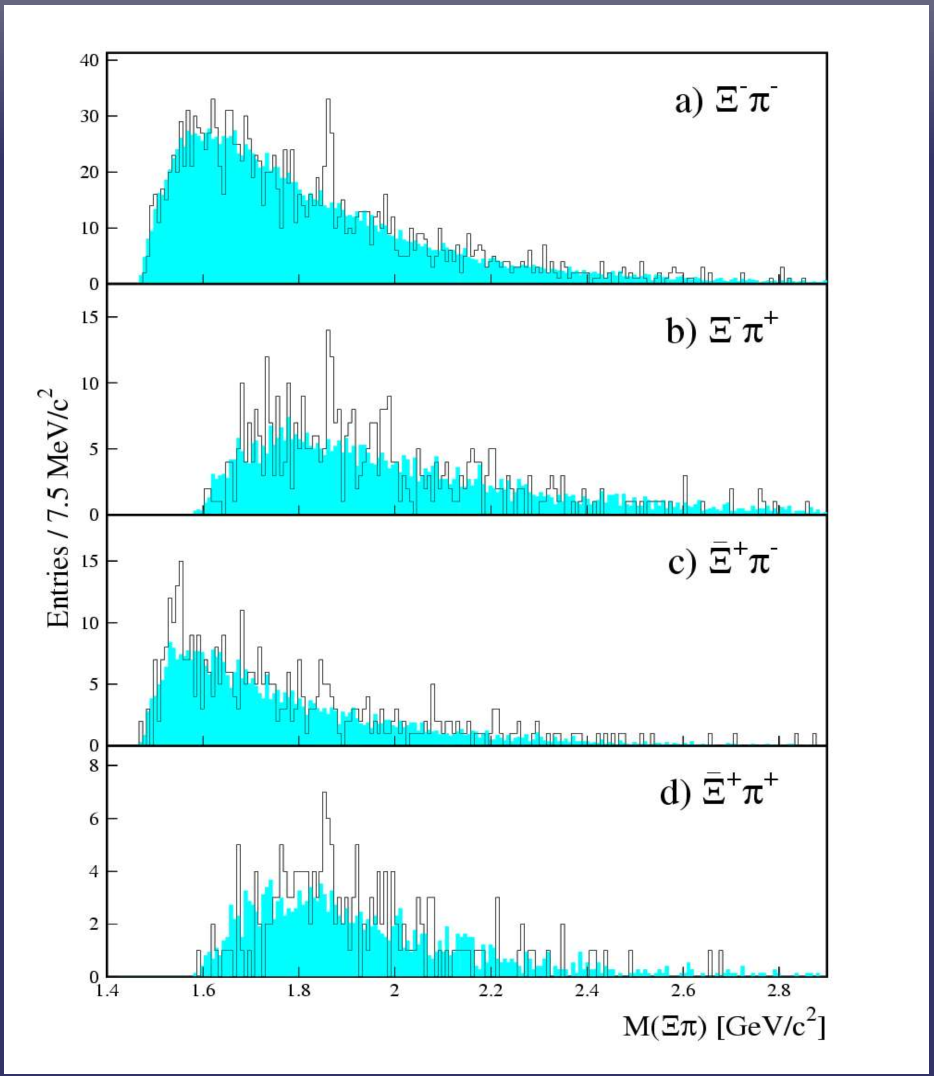
- isospin 1 would lead to 3 states: Θ^0, Θ^+, Θ^{++}
- look at $\Theta^{++} \rightarrow pK^+$ decays

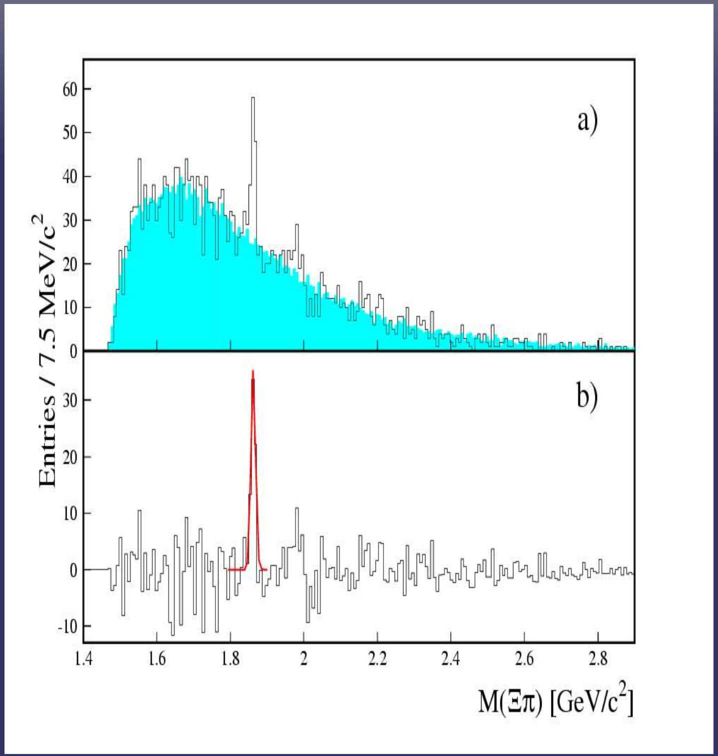
dE/dX was used for both K-mesons and protons

- No Θ^{++}
- Clean $\Lambda(1520)$ D_{03} signal
- $N(\Lambda) \sim N(\bar{\Lambda})$

☞ main source - **fragmentation**

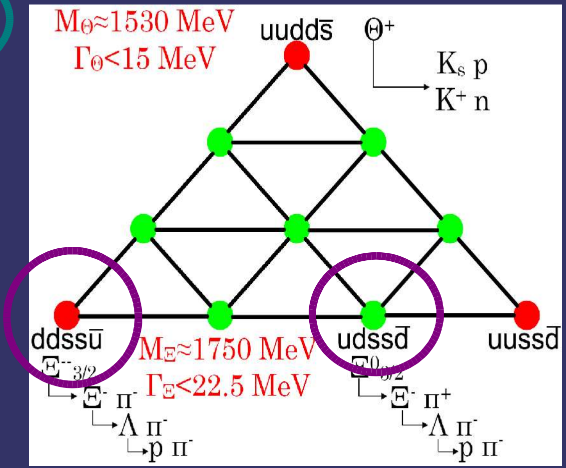
Looking at NA49 signal





mass ~1862 MeV
width < 18 MeV

Summing 4 channels:
-> 5.6 σ confidence

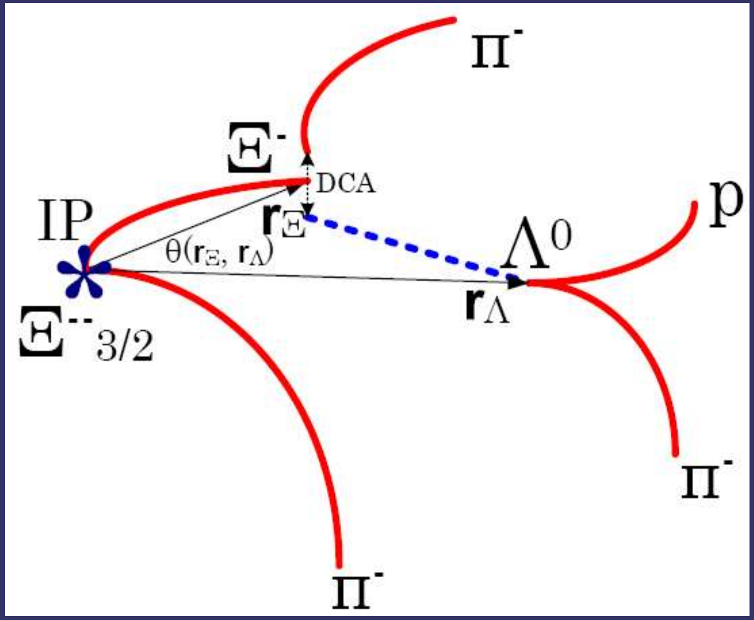


- NA49 – fixed target experiment
- Proton-proton collisions ($\sqrt{s}$=17.2 GeV)
- Large acceptance in the forward region

Looking at the NA49 signal at ZEUS

Similar analysis repeated using ZEUS DIS data:

- 121 pb^{-1}, HERA-I
- e^+p, e^-p collisions
- Q^2>1 GeV^2



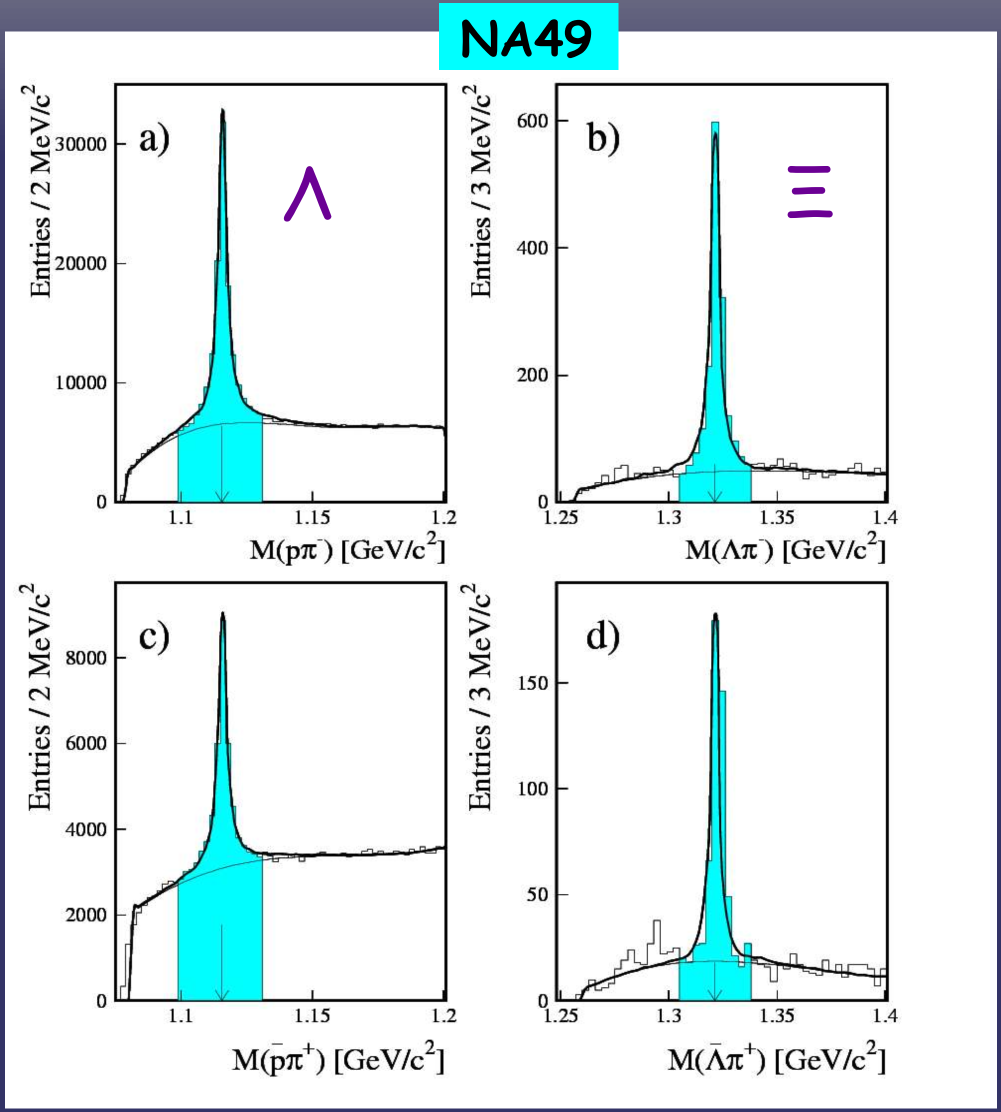
Candidate reconstruction:

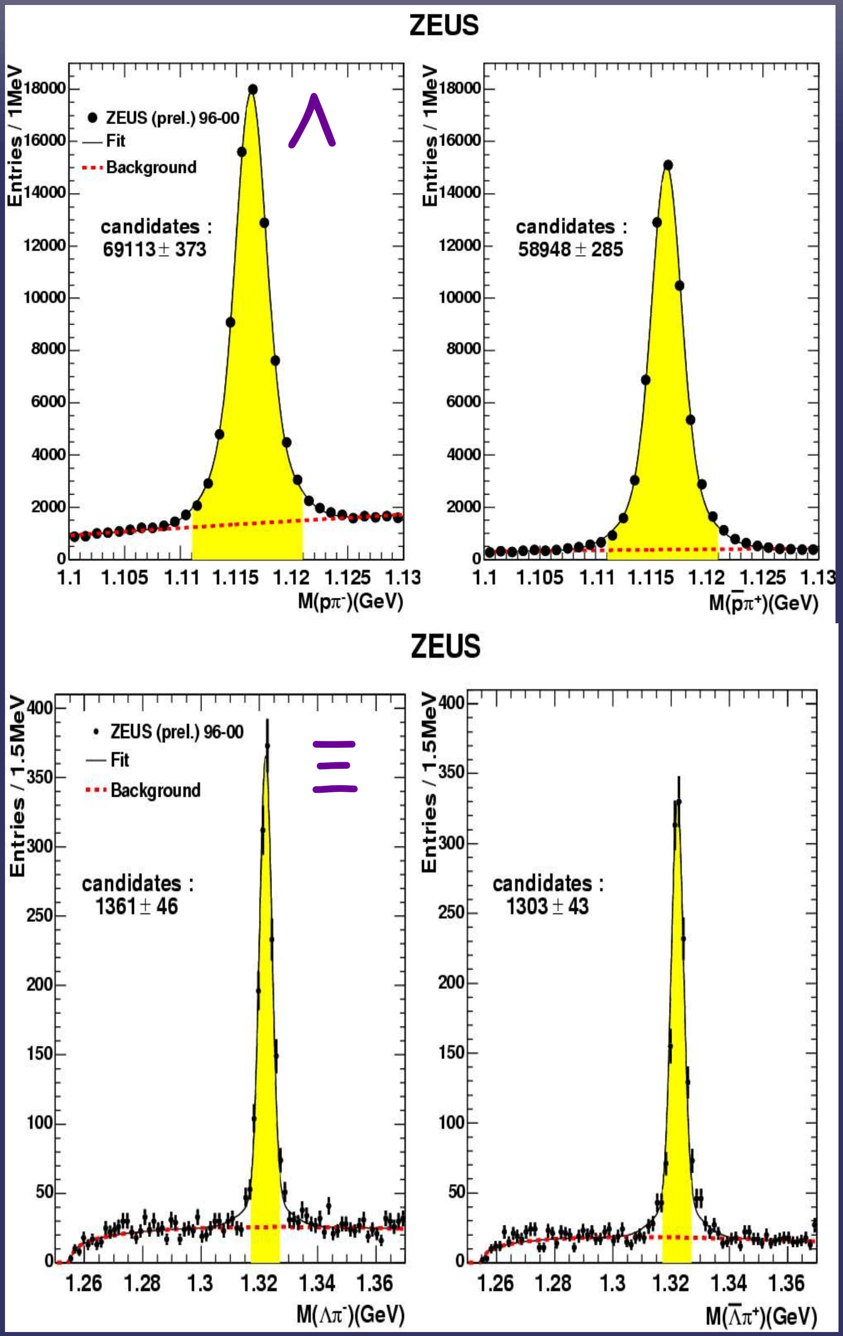
- Step 1: Λ from V0
- Step 2: Ξ from Λπ
  - Use tracks with small DCA (<1 cm)
  - r(Λ)>r(Ξ)
  - r(Ξ)>1.75 cm
- Step 3: combine Ξ with vertex-fitted pion

dE/dX cut for each step to clean the signals

Looking at the NA49 signal at ZEUS

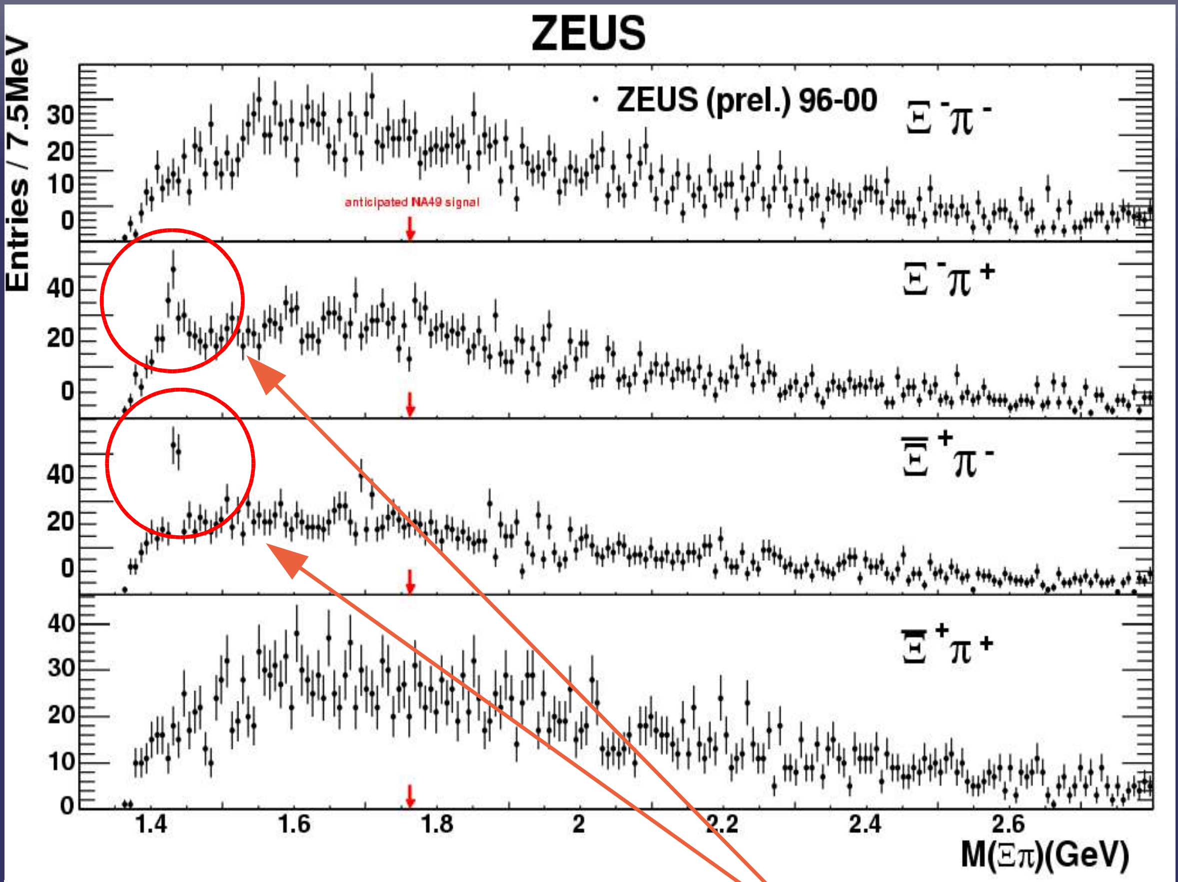
NA49

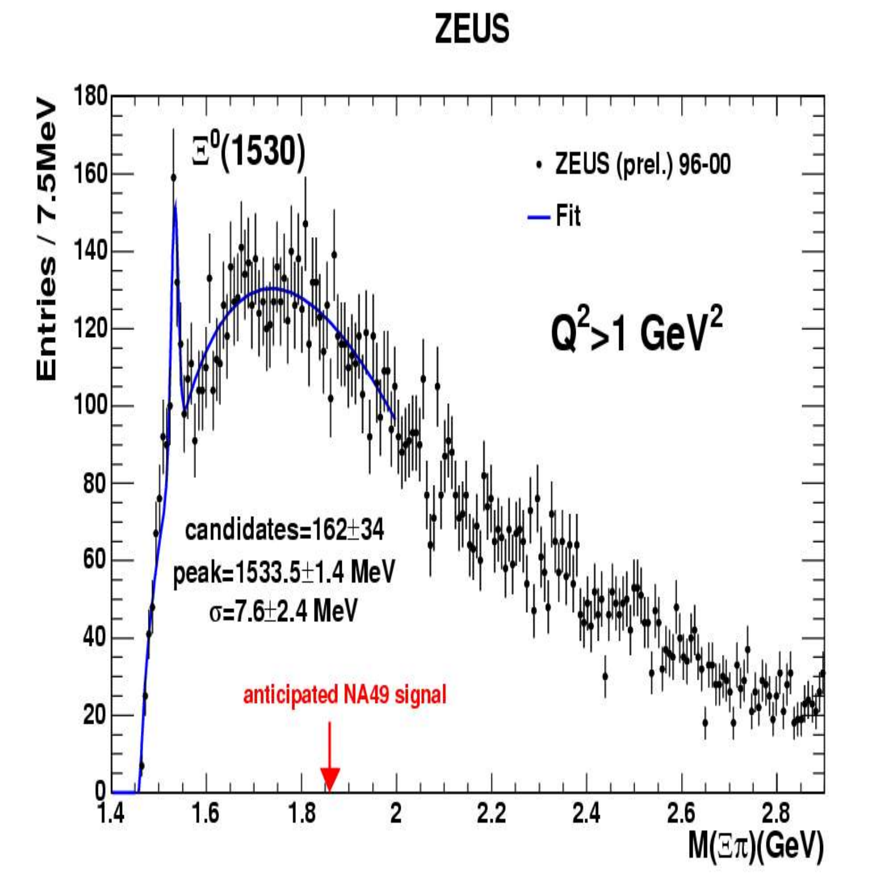


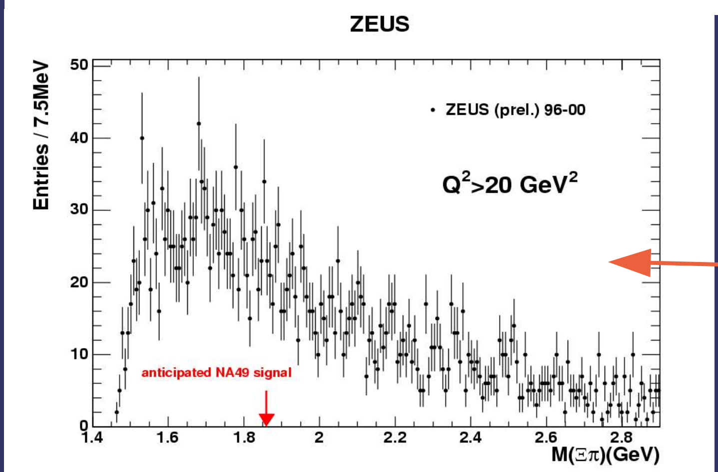


- ZEUS has higher statistics
- Smaller background

Looking at the NA49 signal at ZEUS



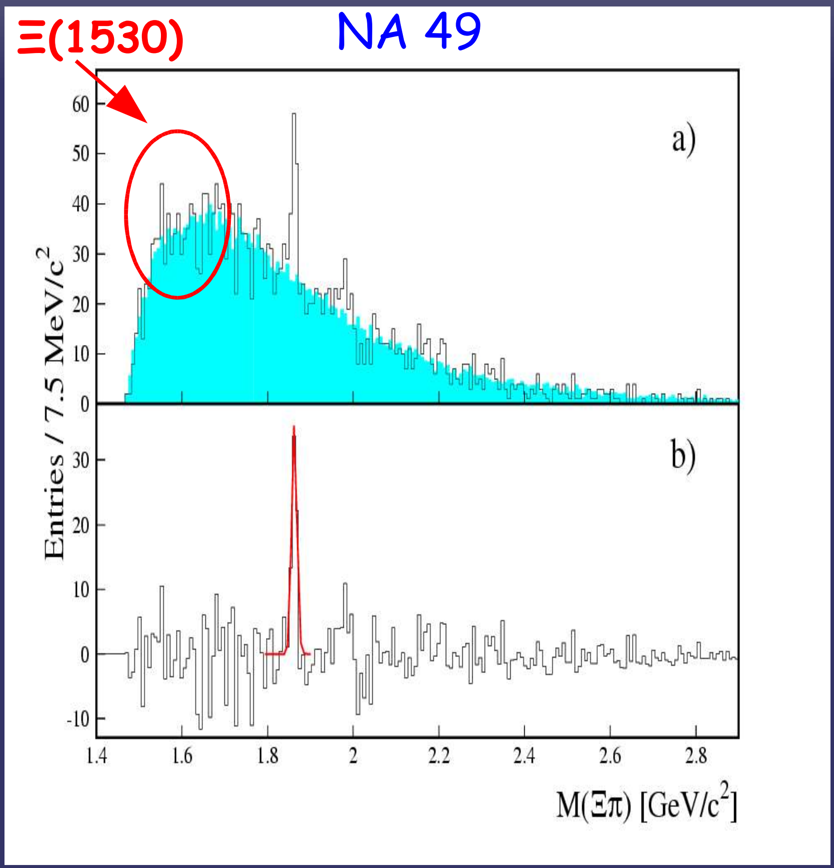


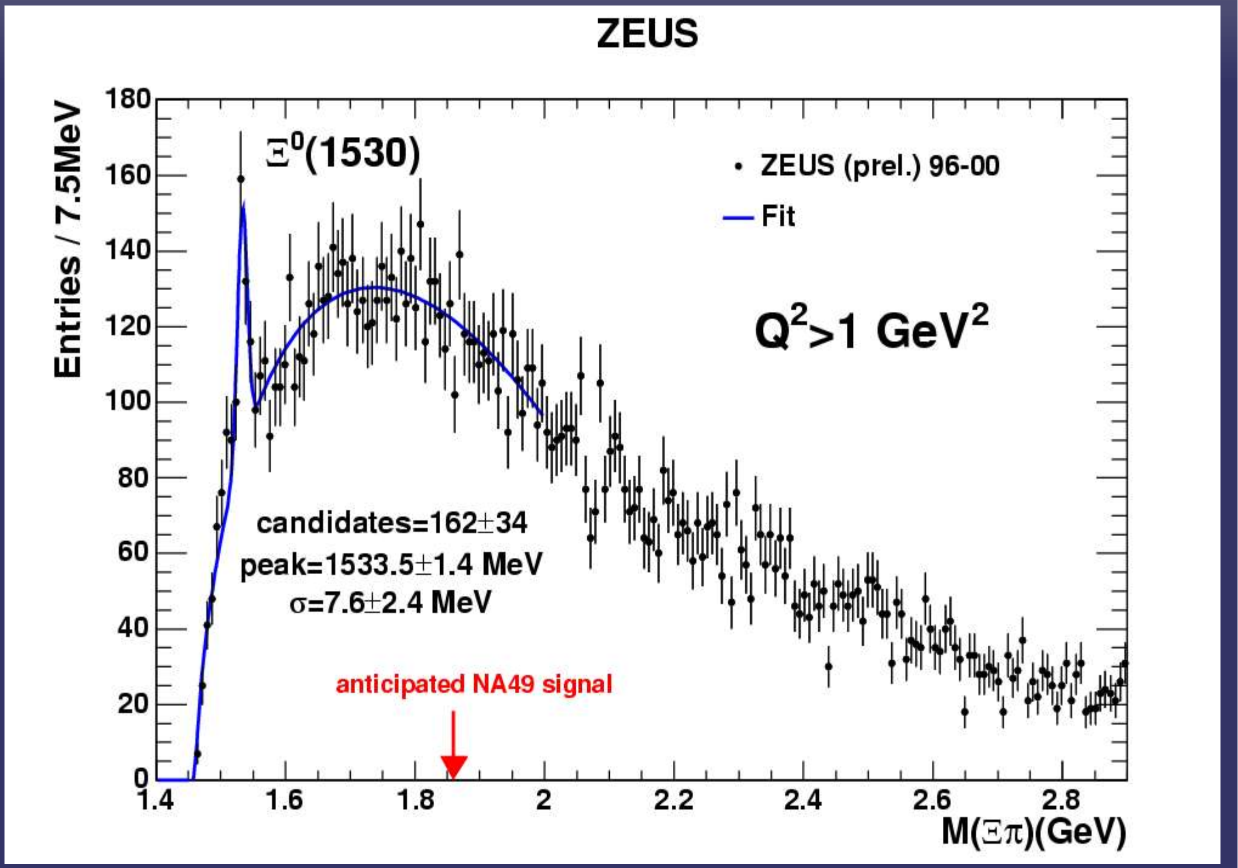


Ξ(1530) P_{13}

- Clean Ξ(1530) P_{13}
- No pentaquark signal
  - for $Q^2>20$ GeV^2 as well !

Looking at the NA49 signal at ZEUS



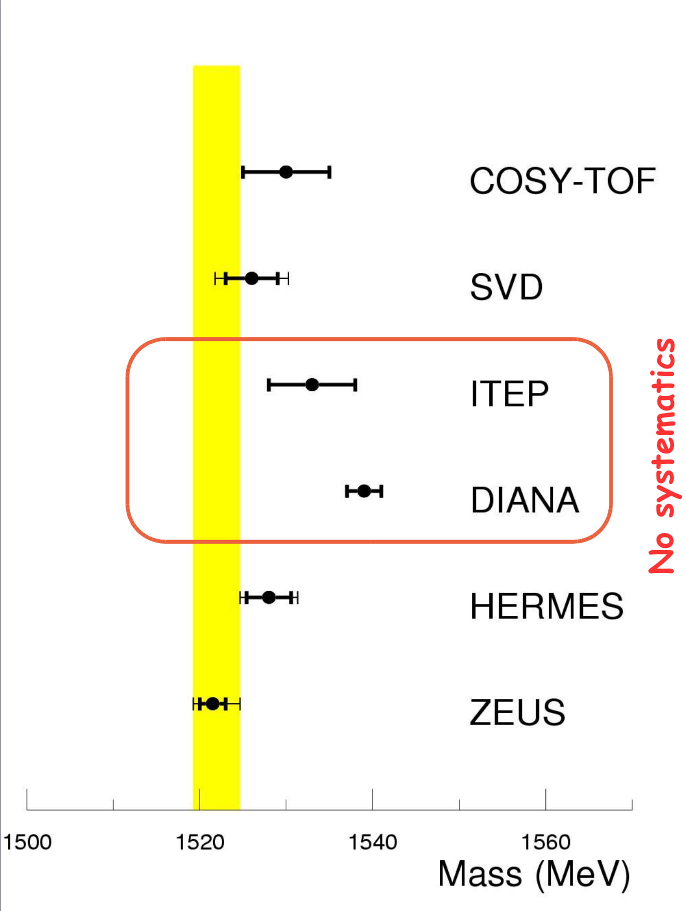


- NA49 signal(pentaquark) / signal(Ξ(1530)) ~ 6-8
- If ZEUS sensitivity to the pentaquark is the same

→ pentaquark signal should not be overlooked

Summary

$K^0_s p$ decay



- Evidence for a new narrow baryonic state at 1522 MeV:
  - mass and width agree with the pentaquark prediction
  - good agreement with other measurements
  - consistent with the exotic K^+n channel:
    - mass ~ 1540-1550 MeV, with ~ 10 MeV errors
  - No $\Lambda\pi$ decay mode
  - No PDG Σ state in this mass range

→ Favor pentaquark explanation

- In this interpretation:
  - first observation of pentaquark in fragmentation region
  - first observation of antipentaquark
- No Θ^{++} peak

- No evidence for the NA49 pentaquark:
  - ZEUS data very competitive: low background, higher statistics, good tracking resolution
  - ZEUS can only miss this signal if it is outside of the detector acceptance (forward region)