H1 search for a narrow baryonic resonance
decaying to $K^0_s p(p\bar{p})$

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Outline:

• Introduction
• Reconstruction of $K^0_s p$
• Results
• Summary
• many observations of baryonic resonances in K+n (exotic) and also in K^0_s p channel
• interpreted as pentaquarks
• also many non-observations

\[ \Theta^+ \rightarrow K^+ n \ \text{exotic} \]
\[ \Theta^+ \rightarrow K^0_s p \ \text{maybe exotic} \]
H1 detector at HERA

$E_e=27.6$ GeV
$E_p=920$ (820) GeV
$\sqrt{s} \approx 300-320$ GeV

Central jet chamber CJC
tracking, particle ID via $dE/dx$
acceptance $-1.75 < \eta < 1.75$
$\eta = -\ln \tan \theta/2$
rec. of $K^0_s$, protons

Lar Calorimeter

Search for state decaying to $K^0_s p(\bar{p})$
• H1 data, 96-00, 75 pb$^{-1}$
DIS events, $5 < Q^2 < 100$ GeV$^2$, $0.1 < y < 0.6$
**K^0_s selection**  
\[ K^0_s \rightarrow \pi^+\pi^- \]

secondary vertices: combinations of oppositely charged tracks  
\[ p_T(K^0_s)>0.3 \text{ GeV}, |\eta| < 1.5 \]

remove combinatorial background and contaminations from \( \Lambda \) decays, photon conversions

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**Inclusive K^0_s signal**  
\[ Q^2 > 5 \text{GeV}^2 \]

![Graph showing inclusive K^0_s signal with fit and data points]

from fit:  
\[ N(K^0_s) \approx 140000 \]
Proton selection via energy loss dE/dx

- resolution for minimal ionizing particles ~8%

- most probable dE/dx: phenomen. parameterisation (Bethe Bloch)

- use likelihoods for separation of protons and π
  large momentum range

- average proton efficiency ~90%
- π-suppression probability 86%
  96 % at low momenta (p<1.5 GeV)
Invariant $K^0_s p(\bar{p})$ mass

visible range: $p_T(K^0_sp) > 0.5$, $|\eta(K^0_sp)| < 1.5$
Invariant $K^0_s \, p(\bar{p})$ mass

visible range: $p_T(K^0_sp) > 0.5$, $|\eta(K^0_sp)| < 1.5$

no significant signal in the interesting mass range 1.52 to 1.54 GeV
Extracting Upper Limits on $\theta^+$ production

- fit background
- background subtraction in integration window $M \pm 10\text{ MeV}, \pm 16\text{ MeV}$
corr. to $2\sigma$ assuming a resolution of $5(8)\text{ MeV}$
- scan $M$ in the range $1.48$ to $1.7\text{ GeV}$
- upper limit on $N(\theta^+)$ (95% C.L.)

$\sigma_{U.L.}(\theta^+\rightarrow K^0 p) = \frac{N_{u.l.}(\theta^+\rightarrow K^0_s p)}{BR \cdot \varepsilon \cdot L}$

- $BR(K^0_s \rightarrow \pi^+ \pi^-) \cdot BR(K^0 \rightarrow K^0_s) = 0.343$
- $L=75\text{ pb}^{-1}$

Signal Monte Carlo
- RAPGAP 3.1
  change decay properties of $\Sigma^*$ to $M=1.52(1.54), \sigma=0$
- detector resolution $\sim 5\text{ MeV}$
- acceptance $\varepsilon \approx 5\%$
Upper Limit (95% C.L.) on $\sigma(ep \rightarrow e\theta X \rightarrow eK^0p(\bar{p})X)$

- $5 < Q^2 < 100$ GeV$^2$, $0.1 < y < 0.6$
- visible range:
  \[ p_T(K^0sp) > 0.5, |\eta(K^0sp)| < 1.5 \]
- different fluctuations in $Q^2$ bins
- 95% C.L. upper limit on cross section
  \[ \sigma_{U.L.}(ep \rightarrow e\theta X \rightarrow eK^0p(\bar{p})X) \sim 40-120 \text{ pb} \]
Upper Limit (95% C.L.) on $\sigma(ep \rightarrow e\theta X \rightarrow eK^0p(\bar{p})X)$

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Upper Limit (95\%C.L.) on $\sigma(ep\to e\theta X\to eK^0p(\bar{p})X)$: charges

- limits for $K^0_s p$ and $K^0_s \bar{p}$ compatible
- fluctuations at different masses for $p$ and $\bar{p}$
Upper Limit (95% C.L.) on $\sigma(ep \to e\theta X \to eK^0p(\bar{p})X)$: charges

Protons:

- Limits for $K^0_sp$ and $K^0_s\bar{p}$ compatible
- Fluctuations at different masses for $p$ and $\bar{p}$

Antiprotons:

- Limits for $K^0_sp$ and $K^0_s\bar{p}$ compatible
- Fluctuations at different masses for $p$ and $\bar{p}$
Comparison with ZEUS

**ZEUS:** signal at 1.522 GeV observed

\[ Q^2 > 20 \text{ GeV}^2, \ 0.04 < y < 0.95, \ p_T > 0.5, \ |\eta| < 1.5 \]

\[ \sigma(\text{ep} \rightarrow e\theta X \rightarrow eK^0 pX) = 125 \pm 27(\text{stat}) +36 -28 (\text{syst.}) \text{ pb (prel.)} \]

\[ \text{dE/dx selection, } p(p_T) < 1.5 \text{ GeV} \]

**low-momentum dE/dx selection:**

- use visual selection of bands in dE/dx, momentum
- dE/dx > 1.15
- proton momentum < 1.5 GeV
**Comparison with ZEUS**

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- dE/dx selection, $p(\text{pr}) < 1.5 \text{ GeV}$

**low-momentum dE/dx selection:**

- use visual selection of bands in dE/dx, momentum
- dE/dx $> 1.15$
- proton momentum $< 1.5 \text{ GeV}$

\[ 20 < Q^2 < 100 \text{ GeV}^2 \]
\[ 0.1 < y < 0.6 \]
**Comparison with ZEUS**

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dE/dx selection, p(pr) < 1.5 GeV

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- dE/dx selection, p(pr) < 1.5 GeV

\[ 20 < Q^2 < 100 \text{ GeV}^2 \]

\[ 0.1 < y < 0.6 \]

**separate charges:**

- invariant \( K^0s \ p \) mass
- invariant \( K^0s \ \bar{p} \)

**low-momentum dE/dx selection:**

- use visual selection of bands in dE/dx, momentum
- dE/dx > 1.15
- proton momentum < 1.5 GeV

\( \frac{dE}{dx} \) selection, p(pr) < 1.5 GeV

\( \frac{dE}{dx} > 1.15 \)

\( \text{proton momentum} < 1.5 \text{ GeV} \)
Comparison with ZEUS

**ZEUS:** signal at 1.522 GeV observed
\[ Q^2 > 20 \text{ GeV}^2, \ 0.04 < y < 0.95, \ p_T > 0.5, \ |\eta| < 1.5 \]
\[ \sigma(\text{e}p \rightarrow \text{e} K^0 \text{pX}) = 125 \pm 27 \text{ (stat)} + 36 - 28 \text{ (syst.) pb (prel.)} \]
dE/dx selection, \( p(\text{pr}) < 1.5 \text{ GeV} \)

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- dE/dx selection, \( p(\text{pr}) < 1.5 \text{ GeV} \)

20 < \( Q^2 \) < 100 GeV^2
0.1 < y < 0.6

separate charges:
invariant \( K^0 s \) \( p \) mass
invariant \( K^0 s \) \( \bar{p} \)
Upper Limit (95% C.L.) on $\sigma(\text{ep} \rightarrow e \theta X \rightarrow e K^0 p(\bar{p})X)$: low p selection

low-momentum $dE/dx$ selection
$20 < Q^2 < 100 \text{ GeV}^2$
$0.1 < y < 0.6$

H1 search for a narrow baryonic $K^0_s p$ resonance, DIS 2005, April 27
Upper Limit (95% C.L.) on $\sigma(ep\rightarrow e\theta X \rightarrow e K^0 p(\bar{p}) X)$: low p selection

low-momentum dE/dx selection
$20 < Q^2 < 100 \text{ GeV}^2$
$0.1 < y < 0.6$

$M = 1.52 \text{ GeV} \; \sigma_{U.L.} \sim 100 \text{ pb}$
Upper Limit (95% C.L.) on $\sigma(ep->e\theta X->eK^0p(\bar{p})X)$: low p selection

low-momentum dE/dx selection
20<$Q^2<$100 GeV$^2$
0.1 < $y$ < 0.6

M=1.52 GeV $\sigma_{U.L.} \sim$ 100 pb *

ZEUS observation:
$Q^2$>20 GeV$^2$, 0.04 < $y$ <0.95, $p_T$>0.5, $|\eta|<$1.5
$\sigma(ep->e^+X->eK^0pX)=125 \pm 27$ (stat) +36 -28 (syst.) pb (prel.)

$\sigma_{U.L.} \sim$ 100 pb not in contradiction with ZEUS measured cross section

* at M=1.522 GeV assuming a resolution of 5 (8) MeV
$\sigma_{U.L.} = 89.6 (116.3)$ pb
Summary

• search for a baryonic resonance decaying to $K^0_s p(\bar{p})$ performed

• no significant signal observed

• 95% C.L. upper limit on cross section in different $Q^2$ ranges

  visible range: $p_T(K^0_s p) > 0.5$, $|\eta(K^0_s p)| < 1.5$

  $\sigma_{U.L.}(e^+ p \rightarrow K^0 p(\bar{p})X) \sim 40 - 120$ pb for $M = 1.48 - 1.7$ GeV

• similar selection and phase space as for the ZEUS analysis

  - no significant signal observed

  upper limit on cross section compatible with the preliminary ZEUS cross section
$K_0^S$ Signal

**Q2>5GeV^2**

Result from fit: (bgr function + 2 gaussians)
N = 142505 ± 430
M = 496.08 ± 0.03 MeV
$\sigma_1$ = 7.06 ± 0.07 MeV
$\sigma_2$ = 17.47 ± 0.02 MeV
Invariant $K^0_s \pi$ mass

- combine $K^0_s$ with primary tracks
- no dE/dx requirement

result from fit: (conv. B.W. and gaussian)

$M = 891 \pm 1$ MeV
(PDG $M = 891.66 \pm 0.26$ MeV)

$N = 18939 \pm 844$ (stat.)

$\Gamma = 50.8$ MeV (fixed)
(PDG $\Gamma = 50.8 \pm 0.9$ MeV)

$s = 7.79 \pm 2.34$ MeV

mass and width agree with expectations
Proton selection efficiency

- Momentum dependent cut on Likelihoods
  - $p \leq 2\text{GeV} : >25\text{hits}, \text{LH}>30\%$
  - $p > 2\text{GeV} : >15\text{ hits}, \text{LH}>10\%$

- Like ZEUS - bands
  - Without cut $p(\text{pr})<1.5$

\[ dE/dx \text{ efficiency described by MC within } \sim 5\% \]

\[ \text{possible differences in } pt \text{ and } \eta \text{ distribution of protons from } \Lambda \text{ or } \theta^+ \]

\[ \text{contribution to systematic uncertainty: } \pm 10\% \]
Proton selection efficiency

- N(K*) before and after dE/dx selection:
  20975 ± 841 K* and 3064 ± 207 K*
  14% of pions survive dE/dx cut
- N(K*) before and after low momentum dE/dx selection, p(pr) < 1.5 GeV:
  17581 ± 792 K* and 681 ± 131 K*
  3.8% of pions survive dE/dx cut

Invariant M(K0sπ), p(pr)<1.5 GeV before and after dE/dx selection:

\[ \text{MK0spisum Q2>2,ST,no dEdx,ppr<1.5} \]

\[ \text{MK0spisum Q2>2,ST,ZEUS dEdx} \]
Limit Extraction

- **Fitting procedure**: 3 different hypothesis
  1) bgr only:
     \[ f(M) = a(M - (m_K + m_p))^b \exp(- (M - (m_K + m_p)c) \]
  2) exclude signal region from fit
  3) bgr + gaussian signal

- Upper limit on \( N \) (95% C.L.):
  \[ N + 1.64\sqrt{N} \]

- Upper limit on \( N(\theta^+ \) (95% C.L.):
  \[ \frac{\max(N - Nbgr,0) + 1.64\sqrt{N}}{0.95} \]
  95% C.L.
  Extrapol from 2σ
Detector resolution estimated from Signal MC

No dE/dx selection

RAPGAP3.1
changed decay properties of $\Sigma^*$
$\theta^+ \rightarrow K^0_s \ p$ at $M=1540$ MeV and $M=1520$ MeV

Fit Result: $M=1520$ MeV
$M=1519.5 \pm 0.1$ MeV
$\sigma=4.323 \pm 0.056$ MeV

Fit Result: $M=1540$ MeV
$M=1539.7 \pm 0.1$ MeV
$\sigma=4.839 \pm 0.084$ MeV

- detector resolution $\sim 5$ MeV

Acceptances (before proton ID):

- $5<Q^2<10$: $M=1520$ 6.52% 7.82% 7.3%
- $10<Q^2<20$: $M=1520$ 6.77% 7.9% 7.64%
- $20<Q^2<100$ GeV$^2$: $M=1520$ 6.52% 7.82% 7.3%

( contribution to systematic error 3% )
### Systematic uncertainties

#### Different fit methods
- bgr function only, full mass range
- bgr function, exclude signal region $M\pm 2\sigma$
- fit bgr + signal (fixed width)

#### Averaging weights
- average weight in Q2 bins (from fit)

#### dE/dx
- efficiency described within 5%

#### Trigger efficiencies S2/S61 (corrected by using MC)
- discrepancy of up to 8%

#### Tracking
- single tracks: 1.8% uncertainty, 3 tracks ~6%

#### e reconstruction

#### Model dependence
- difference between signal MC $M=1520$ and $M=1540$

#### Lumi

**Total increase upper limit by 18.1%**
The HERA accelerator

$E_e = 27.6 \text{ GeV}$

$E_p = 920 \ (820) \text{ GeV}$

ep collisions at $\sqrt{s} \approx 300-320 \text{ GeV}$
Deep-inelastic scattering (DIS) kinematics

- **E_e = 27.6 GeV**
- **E_p = 920 (820) GeV**
- **√s ≈ 300-320 GeV**

**kinematics:**
- **pairs of Lorentz invariants:**
  - 4-momentum transfer squared: \( Q^2 = -q^2 \)
  - Bjorken scaling variable: momentum fraction of proton carried by quark
    \( x = Q^2 / (2 q P) \)
  - inelasticity: \( y = q P / k P \)
  - mass of the hadronic system
    \( W^2 = (P + q)^2 \)

**Kinematic regimes:**
- **\( Q^2 > 1 \text{ GeV}^2 \): DIS**
  scattered e in detector