Meson and Baryon Spectroscopy at HERA

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DESY

for

ZEUS

H1

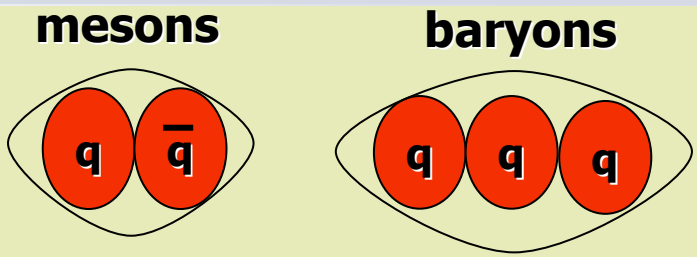
Collaborations

Lake Louise Winter Institute 200
Alberta, Canada
15 – 21 February

1. Introduction
2. Neutral Meson Spectroscopy
3. $K_s K_s$ resonances in DIS
4. $K_s p$ resonances in DIS
5. Summary

Introduction

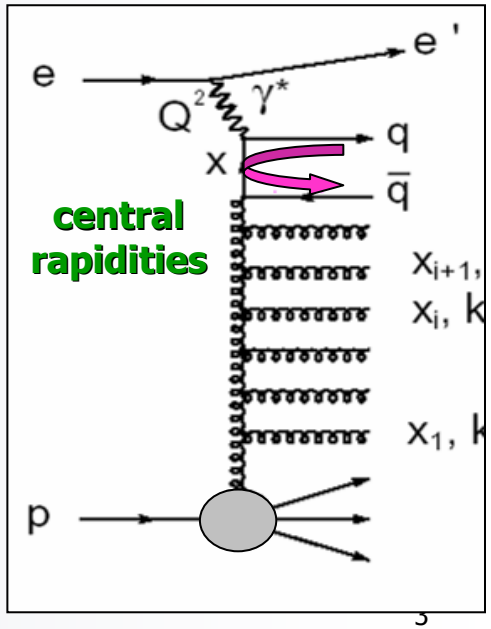
- Constituent quark model



- QCD allows multiquark (> 3q), hybrid (quarks + gluons) and gluonic states → "exotics" in the constituent quark model.
- Hadron spectroscopy → QCD in the non-perturbative regime. How does confinement works? Insight on the degrees of freedom which determine the spectrum of hadrons.
- Powerful tool for testing the QCD bases.

Inclusive Photoproduction of η, ρ^0, $f_0(980)$ and $f_2(1270)$ -- H1

- Insight on long-lived hadron production. Hadronic collisions particle production at central values of rapidity governed only by the properties of the QCD vacuum.
- Production at HERA at similar energy as at RHIC, but in light hadron collisions.
- H1 data, 38.7 pb^{-1}, luminosity at an average photon-proton CM energy of 210 *GeV*

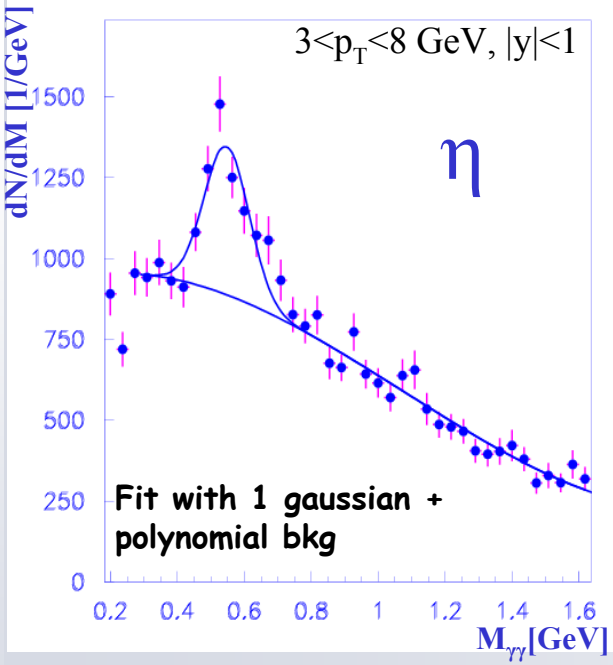


Invariant Mass Distribution

Rapidity limited to |y|<1

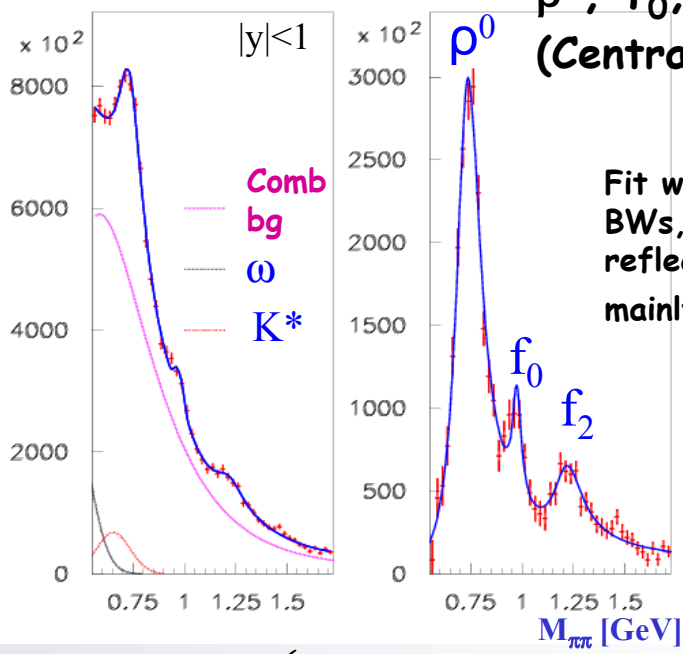
$\eta \rightarrow \gamma\gamma$
(LAr Calorimeter)

H1 preliminary



H1 preliminary

ρ^0, f_0, $f_2 \rightarrow \pi^+\pi^-$
(Central Jet Chamber)

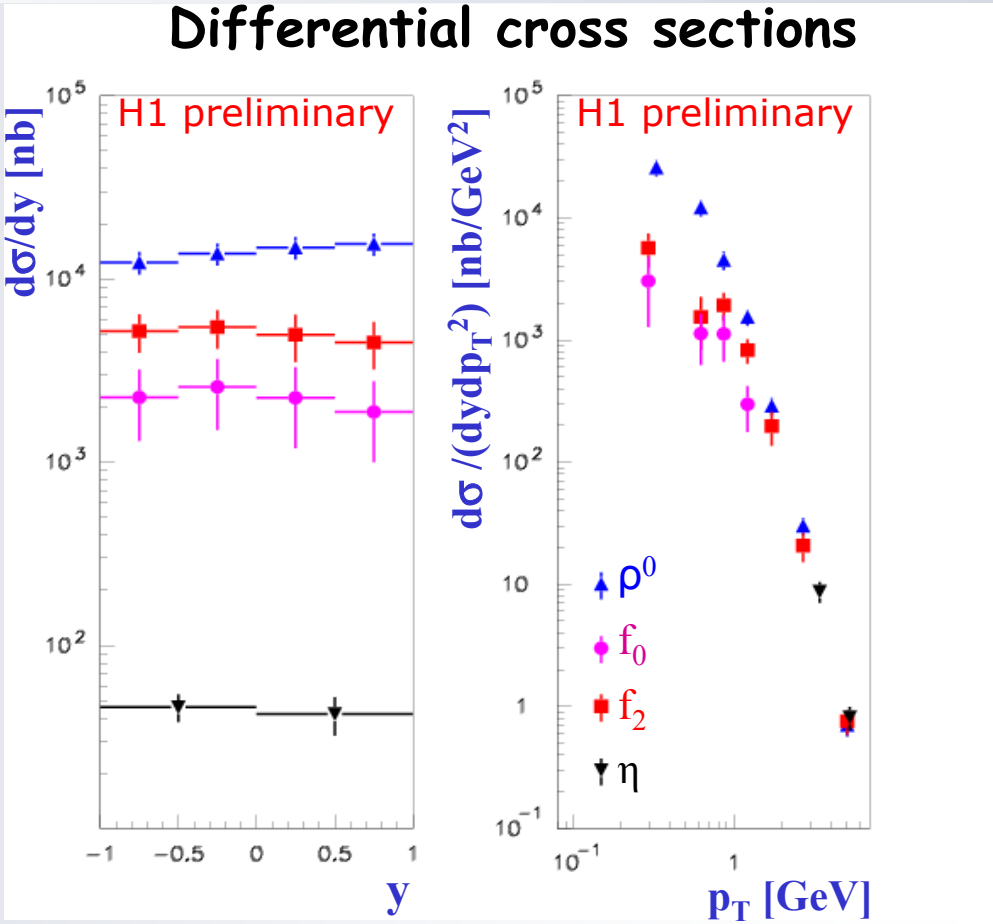


Fit with 3 relativistic BWs, a bkg function and reflection contribution mainly from ω and K*.

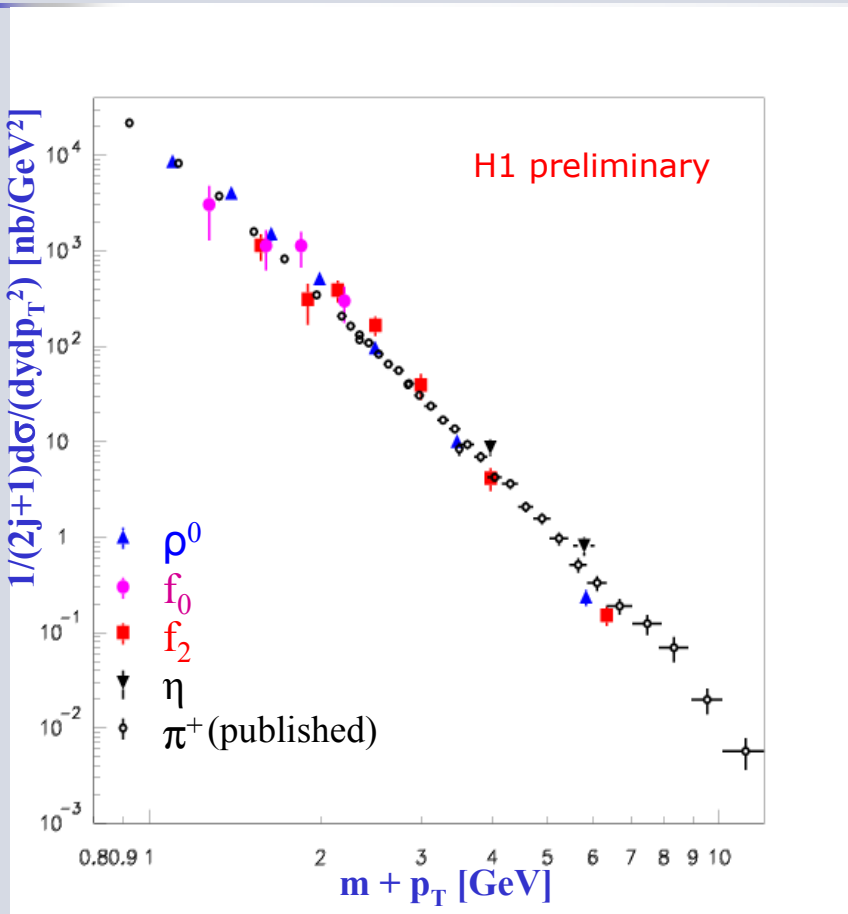
$$F(m) = A\sum_{i=1}^{3}\left(\frac{m_{0,i}m\Gamma_i(m)}{(m^2 - m_{0,i}^{\ 2})^2 + m_{0,i}^2\Gamma_i^2(m)}\right) + a_1(m-2m_\pi)^{a_2}e^{-a_3m-a_4m^2} + \sum(\mathrm{Re}\, f(m))$$

Differential cross section as a function of rapidity (y) and P_T

- **Flat in rapidity.**
- **Power law in p_T compatible with thermodynamic-based approach.**



Differential cross sections as a function of (mass + P_T)

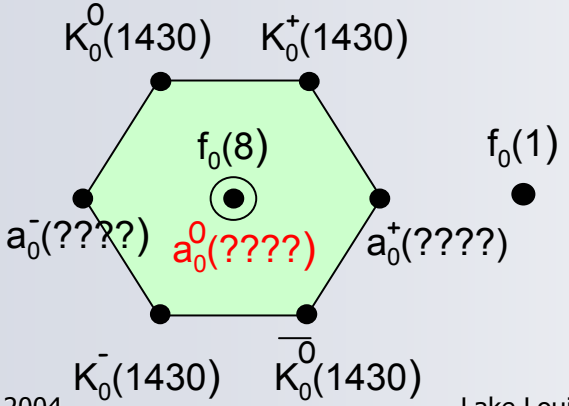


- Cross sections follow similar power law as for pions at same γp collision energy.

- Dependence mainly on the hadron's mass and p_T $\rightarrow$ support universality of long-lived hadron production.

$K_S K_S$ resonances in Deep Inelastic Scattering (DIS) at HERA -- ZEUS

- Scalar meson nonet not well understood; a $s\bar{s}$ state yet to be confirmed, an an excess of candidates for the available positions in the nonet;
- Lattice QCD predicts lightest glueball with $J^{PC}=0^{++}$ and mass between 1.4-1.8 GeV;
- *ep* collisions at HERA as a new environment for resonance studies; gluon ric initial state in *ep* deep inelastic scattering (DIS);
- K^0_S studied at HERA before; clean sample;
- $K^0_S K^0_S$ couples to meson states with $J^{PC}=(\text{even})^{++}$.



Scalar $J^{PC}=0^{++}$ Nonet

$f_0(8)$, $f_0(1)$ mix to:

$f_0(1370) \sim \bar{u}u+\bar{d}d$

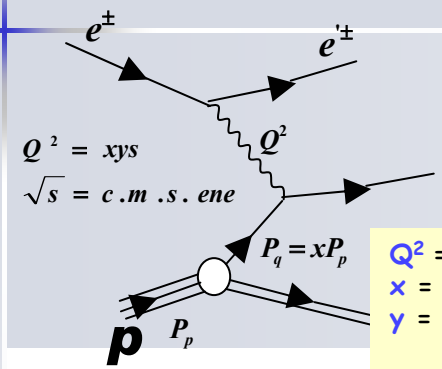
$f_0(1500) \sim$??

$f_0(1710) \sim$??

3 candidates for 2 spots

$f_0(1710)$ is a glueball candidate

Event Selection

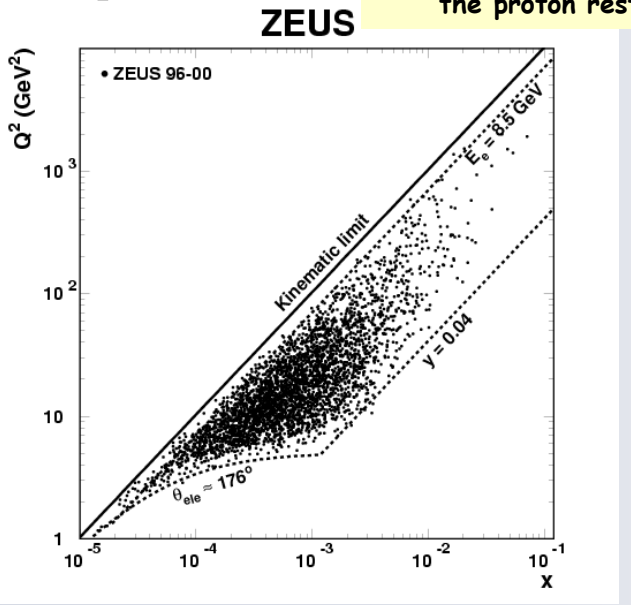


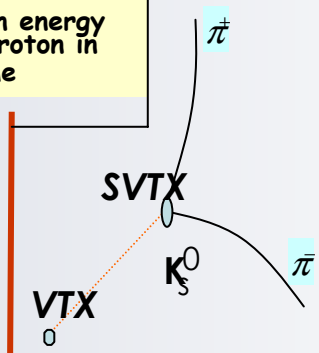
Integrated luminosity of 121 pb^{-1} (1996-2000 data);

Kinematical region limited by event selection requirements and limit fo HERA running with 920 GeV proton

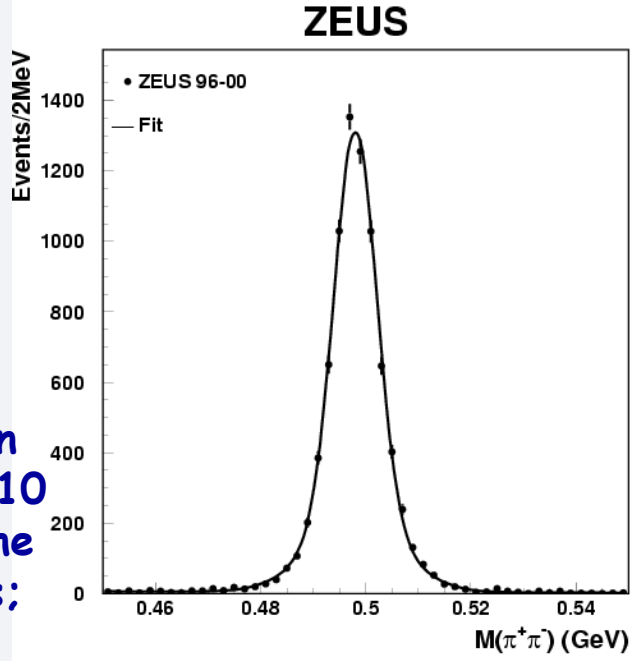
Q^2 = photon virtuality
x = Bjorken scaling variable
y = fraction of the lepton energy transferred to the proton in the proton rest frame

Use the ZEUS Central Tracker Detector

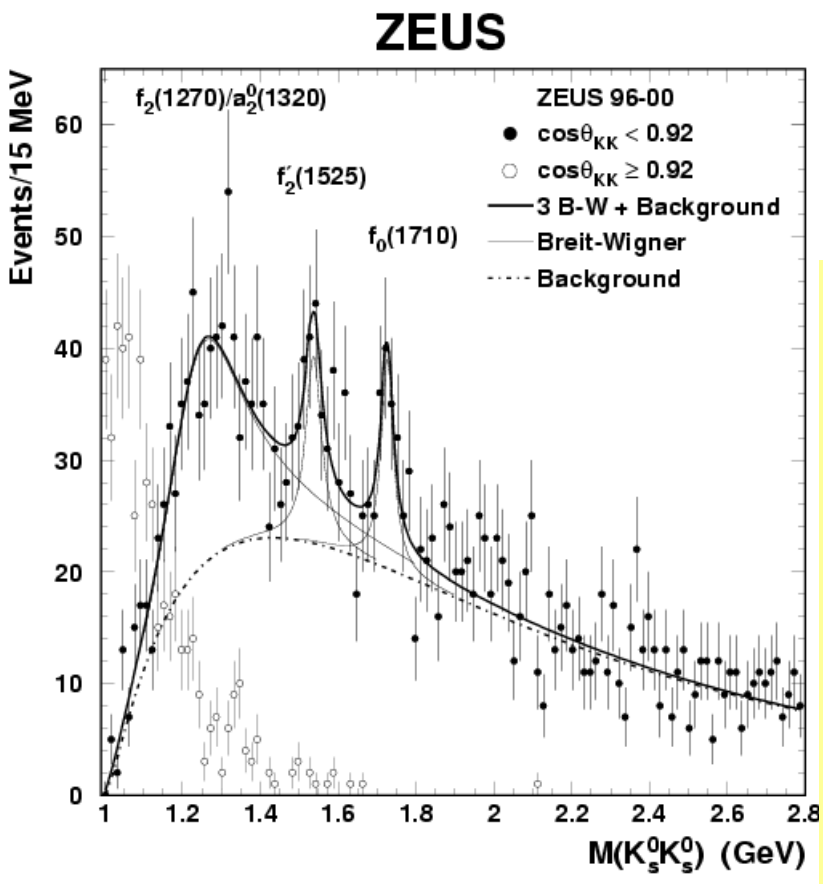




Take only K_s^0 in the region of 10 MeV around the fitted K_s^0 mass;



Results / Discussions

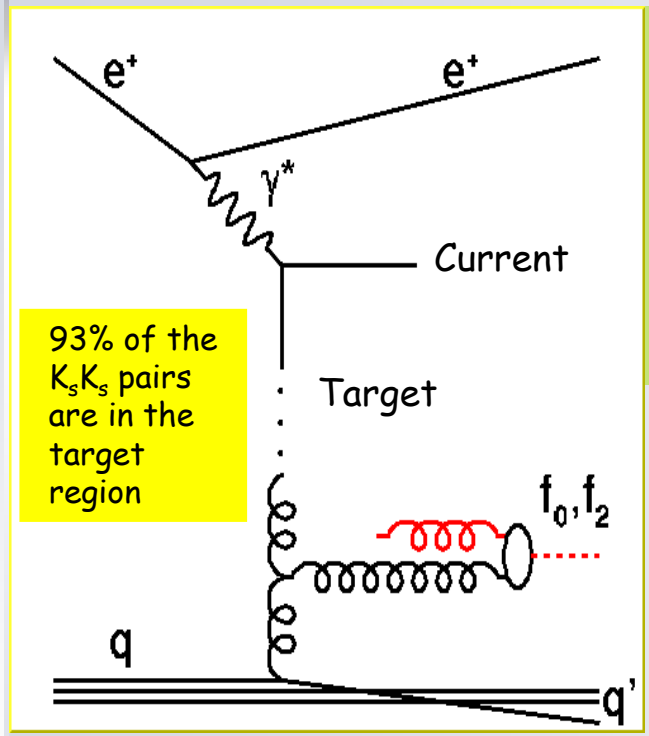


Fit with 3 modified relativistic Breit-Wigners and a background function.

$$F(M) = \frac{dN}{dM} = \sum_{i=1}^{3}\left(\frac{m_{*,i}\Gamma_{d,i}}{(m_{*,i}^2 - M^2)^2 + m_{*,i}^2\Gamma_i^2}\right) + A\left(M - 2m_{K_s^0}\right)^B e^{-C\sqrt{M-2m_{K_s^0}}}$$

- First observation of $J^{PC}=(even)^{++}$ in DIS:
  - a state consistent with $f_2'(1525)$, with peak at 1537^{+9}_{-8} MeV, width of 50^{+34}_{-22} MeV and 84^{+41}_{-31} candidates
  - X(1726) (is this the $f_0(1710)$?) with peak at 1726 ± 7 MeV, width of 38^{+20}_{-14} MeV and 74^{+29}_{-23} candidates
- A third state is observed in the 1300 MeV mass region, consistent with the $f_2(1270)/a_2^0(1320)$ interference.

Results / Discussions

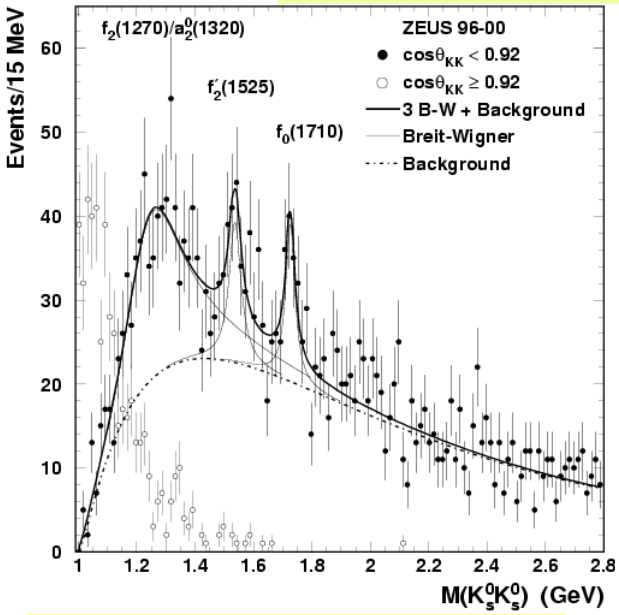


93% of the $K^0_s K^0_s$ production is in a region where sizeable initial state gluon radiation may be expected.

Results / Discussions

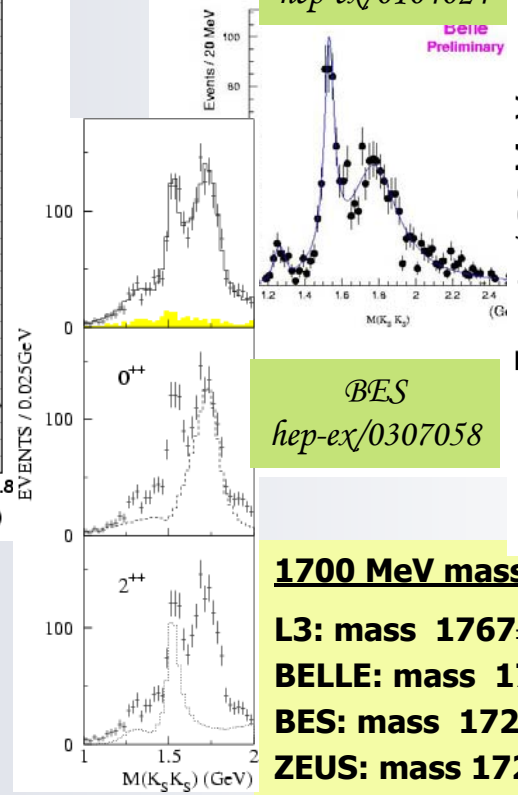
PDG 2002 values (MeV)		mass	width		mass	width
	$f_2'(1525)$:	1525 ± 5	76 ± 10	$f_0(1710)$:	1713 ± 6	125 ± 10

Confronting L3, BELLE, BES and ZEUS



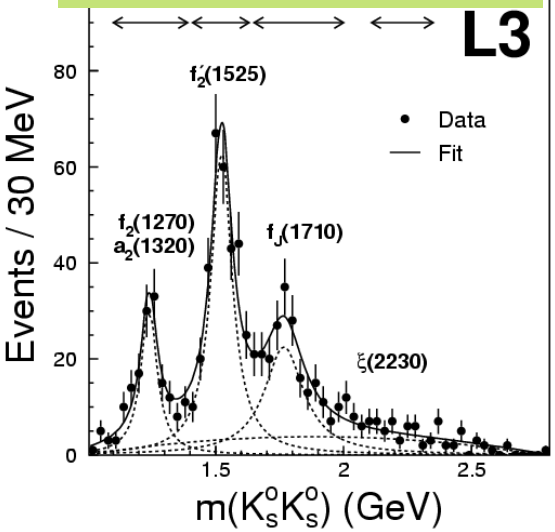
ZEUS
Accepted by Phys. Lett. B
Hep-ex/0308006

BELLE
hep-ex/0104024



BES
hep-ex/0307058

L3
Phys. Lett. B501 (2001) 173-182

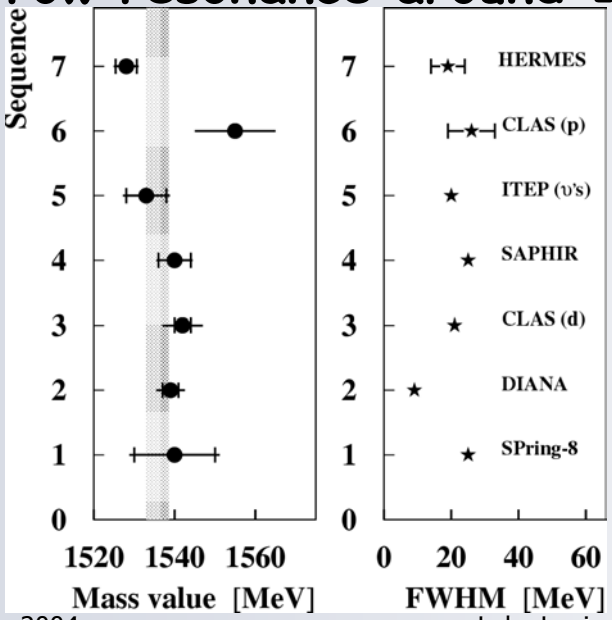


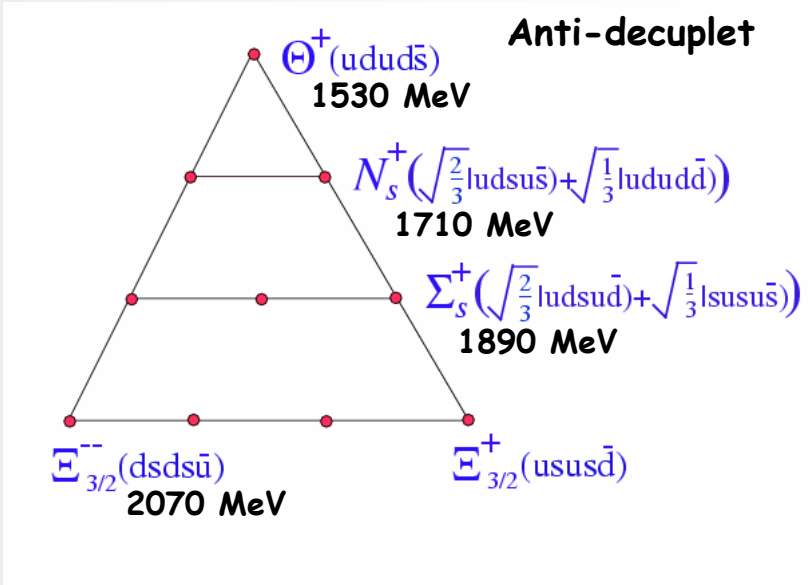
1700 MeV mass region

L3: mass 1767±14 MeV; width 187±60 MeV
BELLE: mass 1768±9.6 MeV; width 323±29 MeV
BES: mass 1722±17 MeV; width 167^{+37}_{-29} MeV
ZEUS: mass 1726±7 MeV; width 38^{+20}_{-14} MeV

Evidence for exotic baryons in $K_S p$ final state in DIS at HERA -- ZEUS

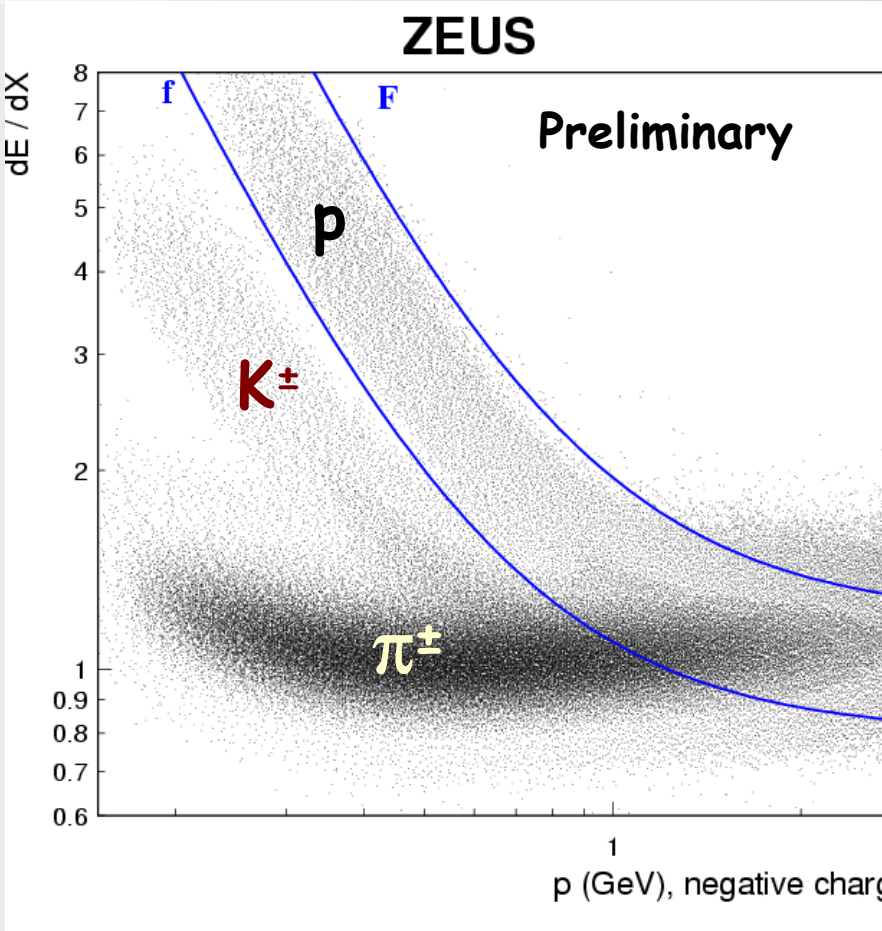
- Recent calculations based on chiral soliton model (Diakonov et al) predict the existence of a narrow S=+1 $uudd\bar{s}$ state Θ^+ with mass around 1530 MeV.
- Some experiments have reported the observation of a narrow resonance around 1530 MeV.



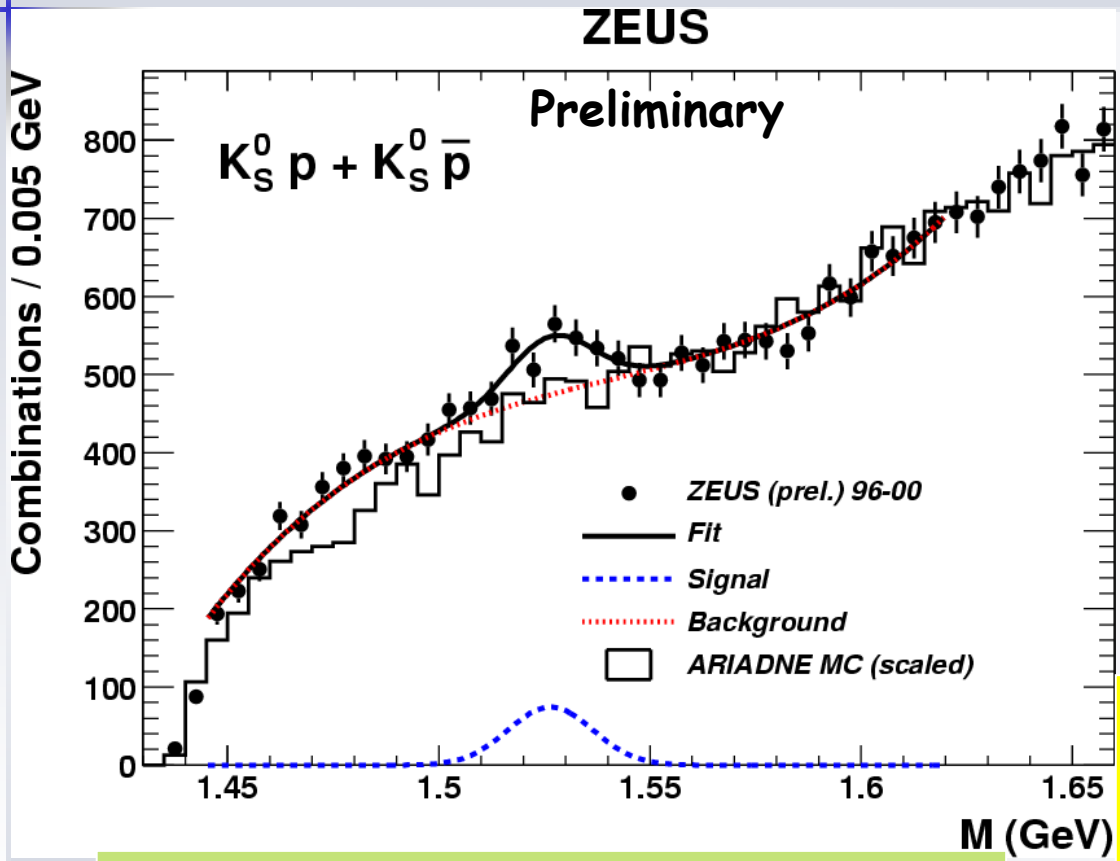


Selection

- Θ^+ can decay to K^0p or K^+n
- Search for $K_s^0 p(\bar{p})$ resonances in inclusive DIS, using 121 pb^{-1} of ZEUS data.
- DIS event selection and K^0 reconstruction similar to those in K_sK_s analysis.
- Use Central Tracker Detector dE/dX to select (anti)proton.



Combined fit

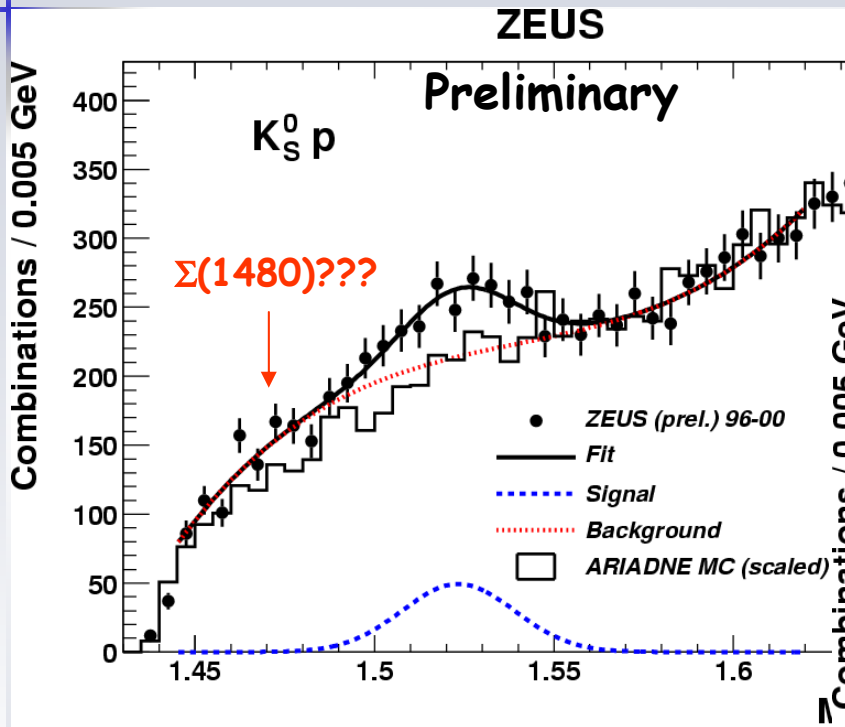


Fit: Gaussian + P3 (free parameters)

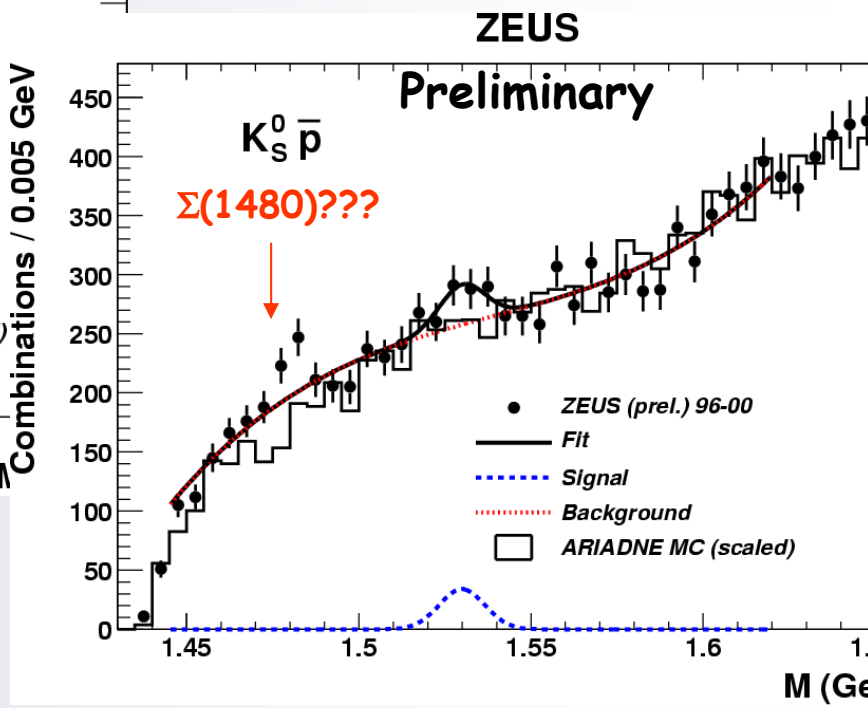
- K_s in the mass region 480-510 MeV.
- (Anti)protons in the dE/dX proton band and with p < 1.3 GeV
- Remove $K^*(892)$ reflection
- Resolution of 5 MeV in the 1530 MeV region

372±75 candidates
Peak at 1527±2(stat) MeV
Width of 10±2(stat) MeV
Significance of ~5σ

Fitting ($K_s p$) and (K_s anti-proton) separately



126±50 candidates
Peak at 1529±3(stat) MeV
Width of 7±3(stat) MeV



393±86 candidates
Peak at 1523±3(stat) MeV
Width of 16±3(stat) MeV

Confronting with other Θ^+ measurements

Experiment	M (MeV)	Γ (MeV)	Significance
SPring8	1540 ± 10 ± 5	< 25	(4.6σ)
DIANA	1539 ± 2 ± "few"	< 9	(4.4σ)
CLAS (d)	1542 ± 2 ± 5	21	(5.3σ)
SAPHIR	1540 ± 4 ± 2	< 25	(4.8σ)
ITEP (*vs*)	1533 ± 5	< 20	(6.7σ)
CLAS (p)	1555 ± 1 ± 10	26 ± 7	(4.3σ)
HERMES	1528 ± 2.6 ± 2.1	19 ± 5 ± 2	(5.6σ)
ZEUS (Prel.)	1527±2	10±2	(5.0σ)

Summary

Three results were reported in hadron spectroscopy:

✓ **Neutral meson spectroscopy**

- First measurement of cross section for inclusive photoproduction of η, ρ^0, $f_0(980)$ and $f_2(1270)$ at γp average energy of 210 GeV;
- Differential spectra similar to those of light, long-lived hadrons.

✓ **K_sK_s resonances in DIS**

- First observation of resonances in K_sK_s final state in DIS was reported;
- A state is observed at 1537^{+9}_{-8} MeV, consistent with the $f_2'(1525)$;
- Another state X(1726) is observed at 1726 ± 7 MeV, probably the $f_0(1710)$ (glueball candidate). More stat. is needed to establish its widt
- States are in a region where sizeable initial state gluon rad. is expected

✓ **K_sp resonances in DIS**

- $K_s^0 p(\bar{p})$ was studied in inclusive DIS sample at HERA;
- A signal is observed at 1527±3 MeV with width of 10±2(stat) MeV, consistent with the predicted Θ^+ pentaquark;
- First evidence for pentaquark in HEP colliding experiment;
- Evidence for anti-pentaquark ($K_s^0 \bar{p}$).