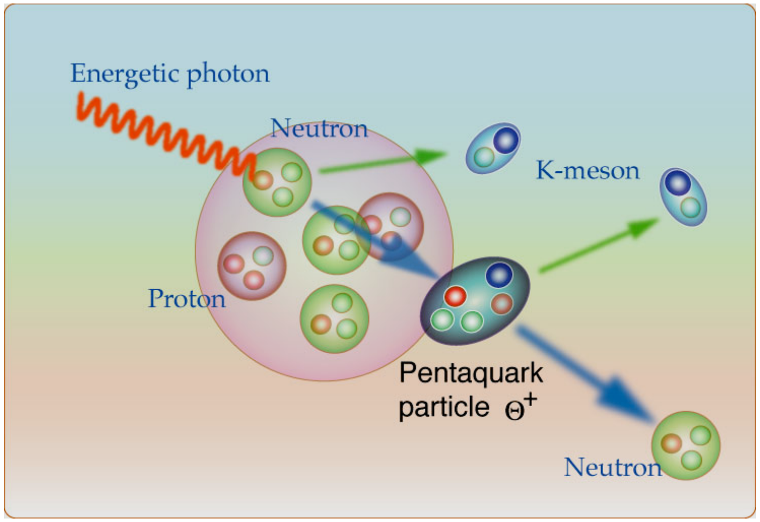
Pentaquark: Fact or Fancy

Patrizia Rossi
Laboratori Nazionali di Frascati - INFN



Outline

- Introduction
- Experimental Overview
- Comments on positive and null results
- Dedicated Experimental Program @ JLab
- Conclusion

The CLAS collaboration has decided that results will be presented

only when final

Normally, preliminary results would be shown, but these are not normal circumstances.

Introduction

Known HADRONS

bound states of three quarks(qqq) : **BARYONS**

quark and anti-quark($q\bar{q}$) : **MESONS**

QCD: predicts the existence of mesons and baryons with more complicated internal structure.

non-conventional mesons : ggg(glueballs), $q\bar{q}g$ (hybrids), $q\bar{q}q\bar{q}$

non-conventionale baryons: qqqg, $qqqq\bar{q}$

Pentaquarks

- Baryons whose minimum quark content is 4 quarks and 1 antiquark
- "Exotic" pentaquarks are those where the antiquark has a different flavor than the other 4 quarks ; quantum num. cannot be defined by only 3 quarks

Ex: $uuds\bar{s}$, non-exotic — Baryon number = 1/3 + 1/3 + 1/3 + 1/3 – 1/3 = 1; Strangeness = 0 + 0 + 0 — 1 + 1 = 0

Ex: $uudd\bar{s}$, exotic — Baryon number = 1/3 + 1/3 + 1/3 + 1/3 – 1/3 = 1; Strangeness = 0 + 0 + 0 + 0 + 1 = +1

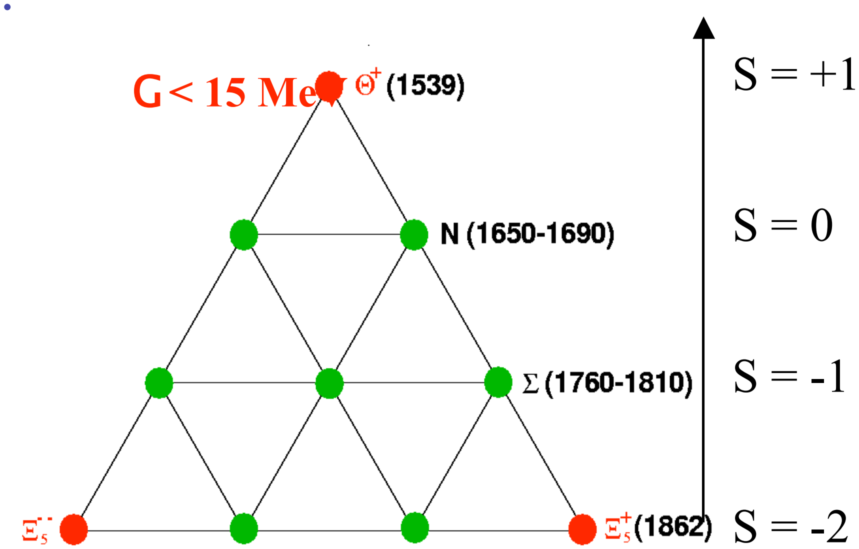
Introduction

Before 2003

There were searches in the 1960's and1970's mostly in bubble chamber experiments with incident π and K beams for what was then referred to as the Z*, a baryon with positive strangeness. Those experiments found no enhancements in S=+1 baryon channels. Indeed the failure to find such flavor exotic baryons lent credence to the then nascent quark model.

After 2003

.....Hadronic Physics has been very interesting



Spectacular Development

1987 First prediction of the mass: **Mass Z$^+$ (uudds*) = 1530 MeV**

Preszalowicz, Chiral Soliton Model, World Scient. '87, p. 112

1997 First prediction of the width: **Γ < 15 MeV**

Diakonov, Petrov, Polyakov, Chiral Soliton Model, Z. Phys. A 359(1997)305

Mass of Z$^+$ (uudds*) = 1530 MeV, Spin=1/2, Isospin=0, Parity +, S=+1.

The **width prediction** was the key for the experimental discovery of a Θ^+ candidate in 2003

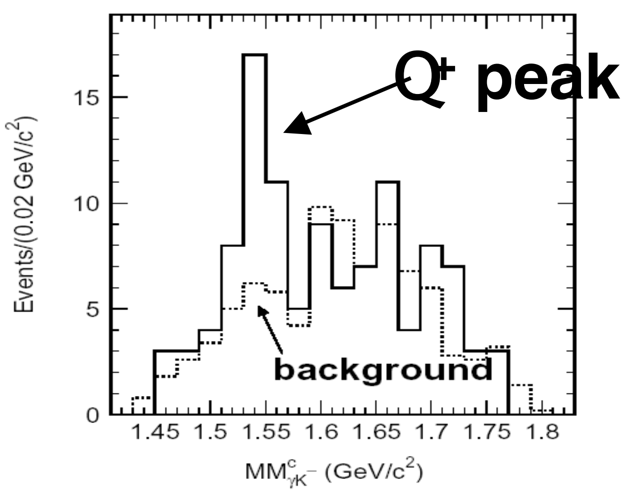
2003 First observation of Z$^+$ renamed Θ^+: **Mass 1540 ±10 MeV**

LEPS Collaboration, T Nakano et al, PRL91 (2003) 012002

Photoproduction on bound neutron in ^{12}C

g n → Q$^+$ K$^-$ Q$^+$ → K$^+$ n

Q$^+$ signal in the invariant mass of K$^+$n system



N$_Q$ = 19.0±2.8

N$_B$ = 17.0±2.8

M$_Q$ = 1.54 ± 0.01 GeV

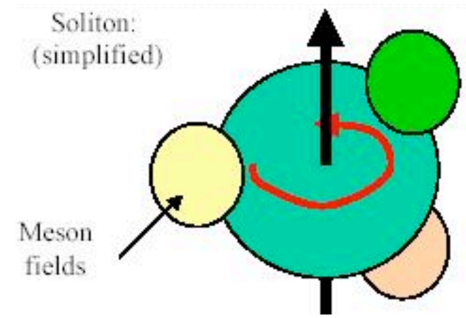
G$_Q$(FWHM) = 25 MeV

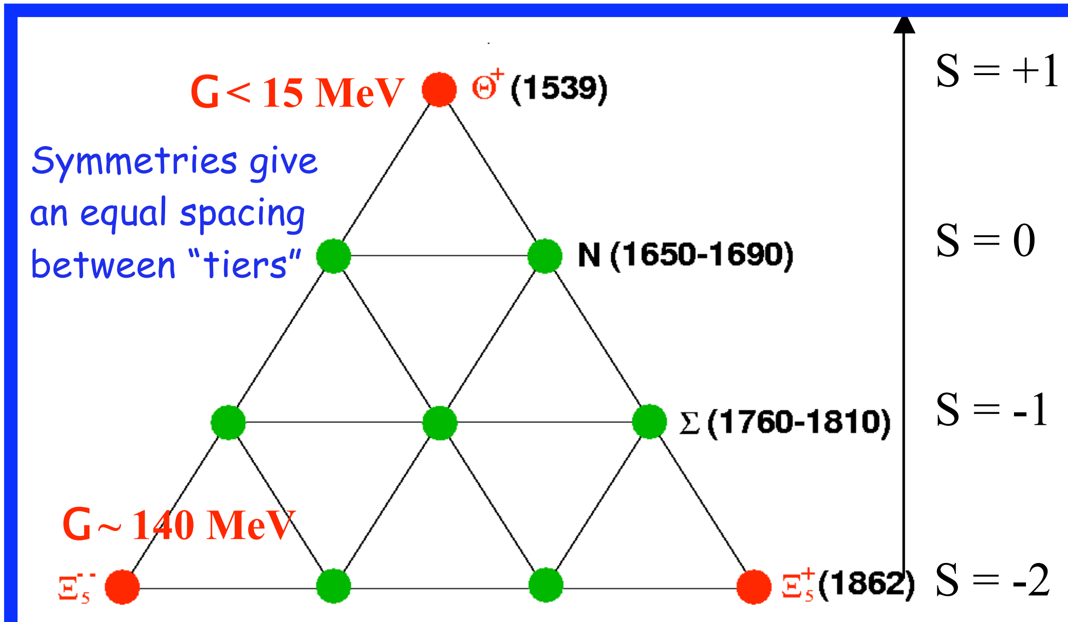
Gaussian sig. S= 4.6s

Pentaquark in the Chiral Quark Soliton Model

- Soliton: rigid core (q^3) surrounded by meson fiels ($q\bar{q}$)
- Barions are rotational states of the soliton nucleon in spin-isospin space

1st eccited state : [8] J=1/2
2nd " : [10] J=3/2
3rd " : $[\overline{10}]$ J=1/2 exotic (N*(1710) fixes all the masses)





- Diakonov et al. - Z. Phys. A359 (1997) 305
- D. Diakonov, V. Petrov, arXiv:hep-ph/0310212

- Definite predictions about masses & widths of the states
- Presence of three states with explicit exotic quantum numbers
- Width very narrow
  - → directly visible in measured invariant masses
  - → No complicate p.w.a.needed

Where we are now

Before 2003 searches for flavor exotic baryons came up empty but now we have claims for:

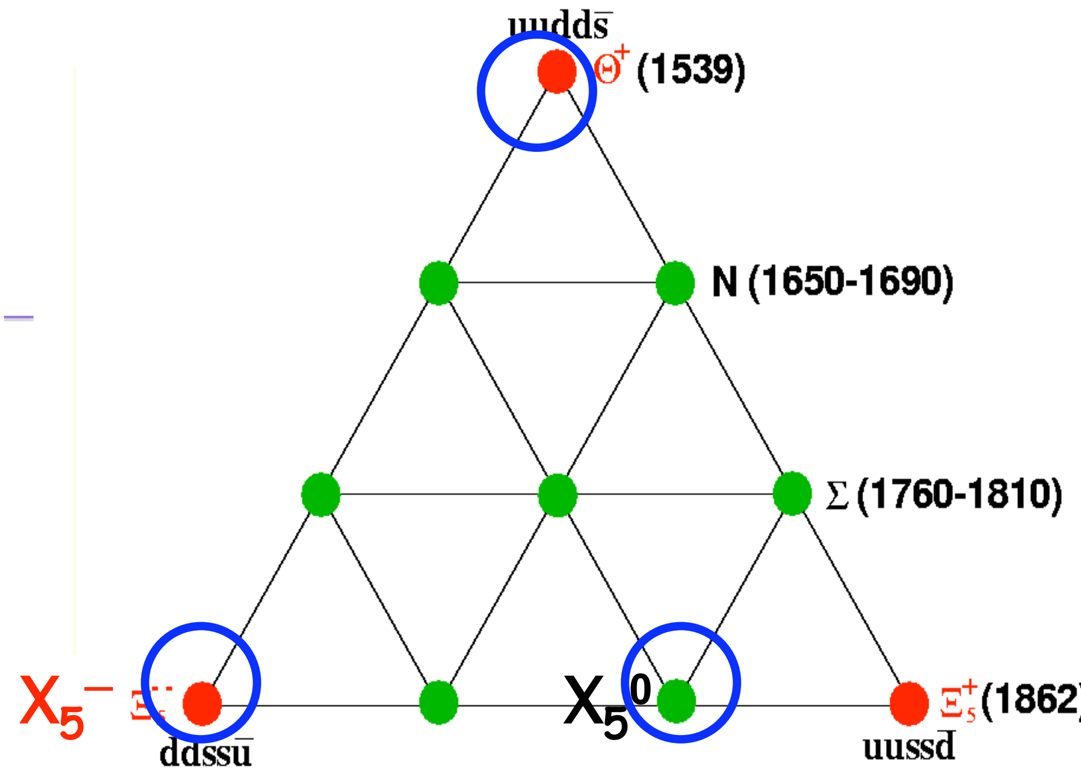
$$\theta^+(1540) \longrightarrow K^+ n$$

$$\theta^+(1540) \longrightarrow K^0_S p$$

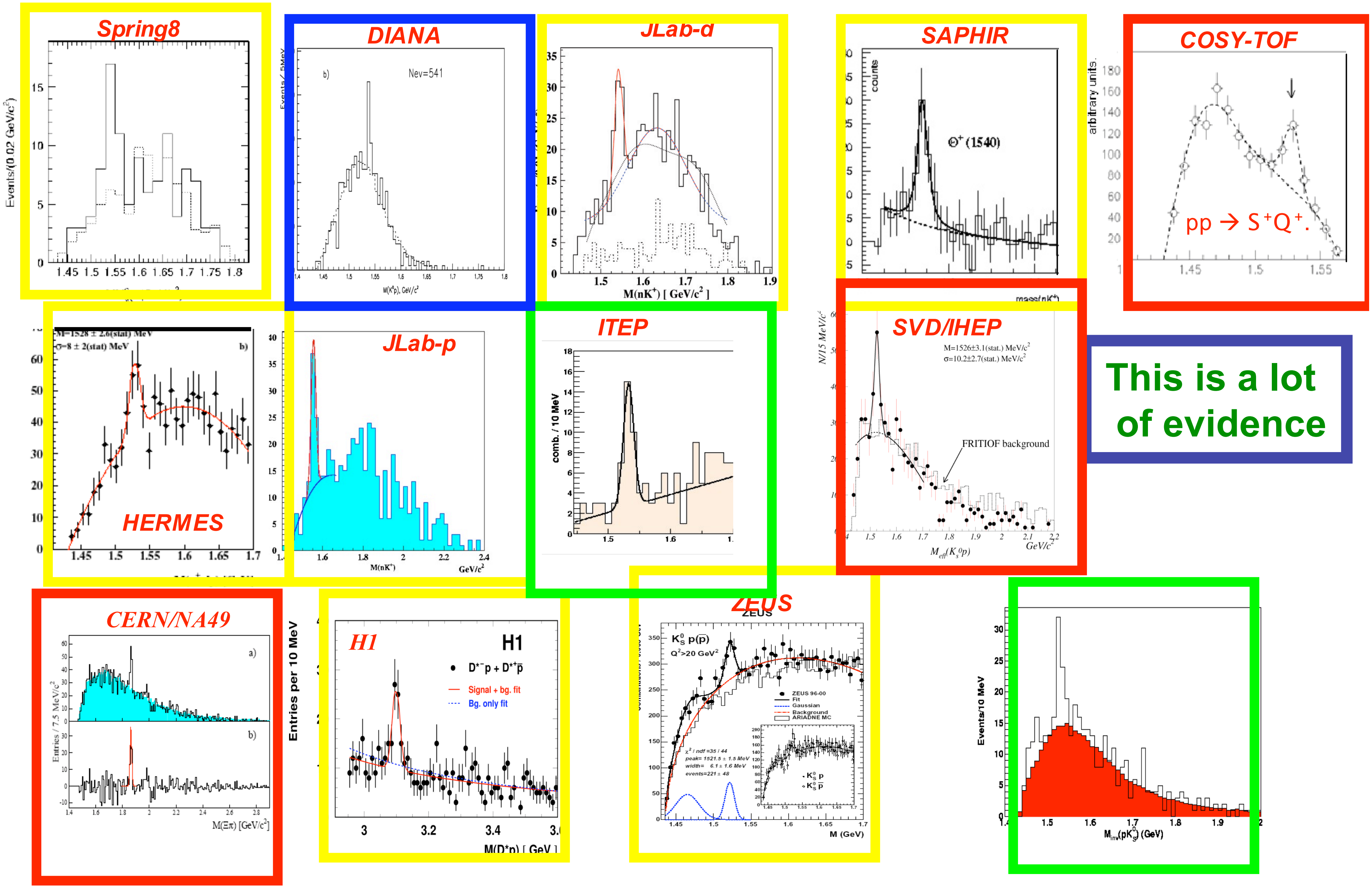
$$\Xi^{--}(1862) \longrightarrow \Xi^- \pi^-$$

$$\Xi^0(1862) \longrightarrow \Xi^- \pi^+$$

$$\theta_c(3100) \longrightarrow D^{*-} p$$



Evidence for Pentaquark States

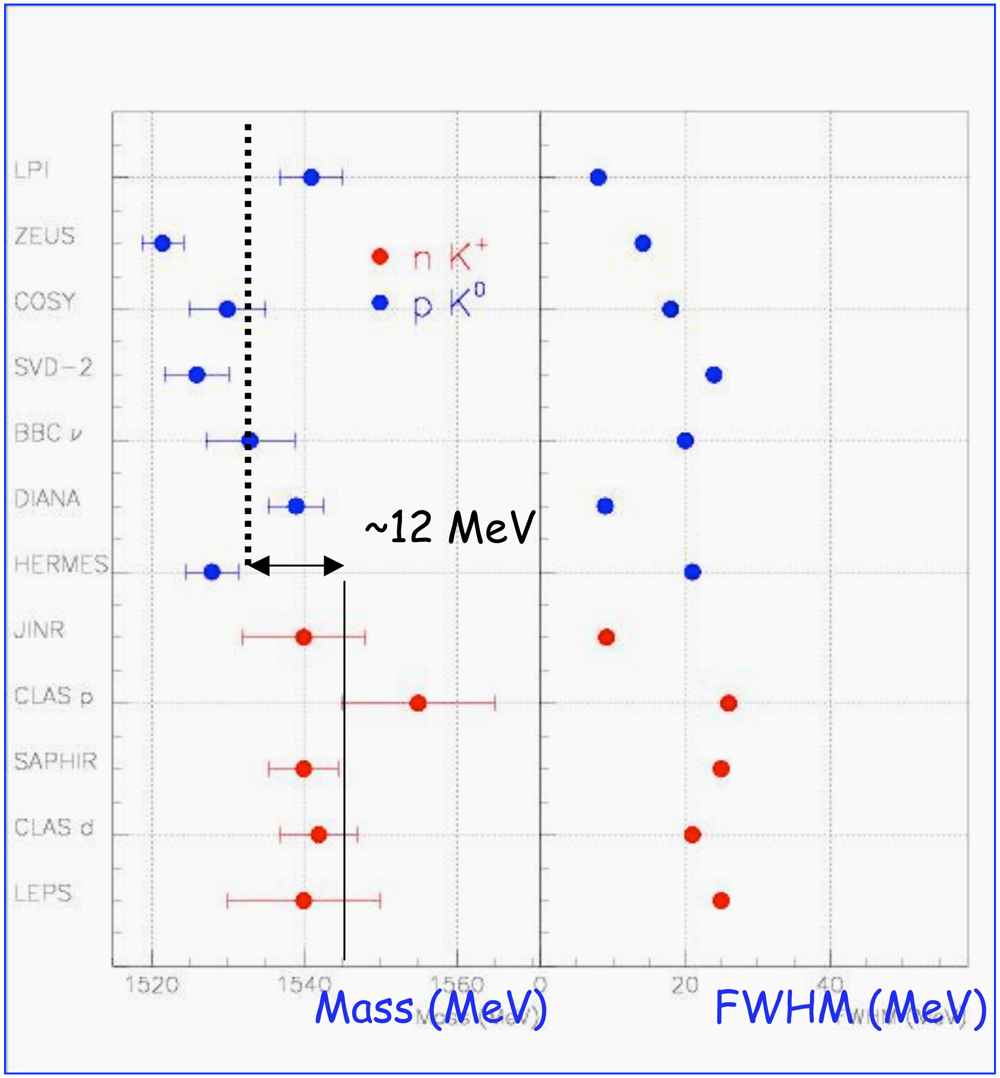


This is a lot of evidence

Positive Results

LEPS PRL 91(2003) 012002	$\gamma C_{12} \rightarrow K^- K^+ n$ Θ^+ $K^+ n$	**SVD** hep-ex/0401024	$pA \rightarrow K^0 pX$ Θ^+ $K^0 p$
CLAS PRL 91(2003) 252001 PRL 92(2004) 032001	$\gamma d \rightarrow K^+ K^- np$ Θ^+ $\gamma p \rightarrow K^+ K^- n\pi^+$ $K^+ n$	**ITEP (ν)** Phys. Atom. Nucl. 67 (2004) 682	$\nu A \rightarrow K^0 pX$ Θ^+ $K^0 p$
SAPHIR Phys. Lett. B572(2003)127	$\gamma p \rightarrow K^0 K^+ n$ Θ^+ $K^+ n$	**JINR** hep-ex/0403044 hep-ex/0404003 hep-ex/0410016	$p+C_3H_8 \rightarrow K^0 pX$ Θ^+ $np \rightarrow npK^+K^-$ $K^0 p$
DIANA Phys. Atom. Nucl. 66 (2003) 1715	$K^+ Xe \rightarrow K^0 pXe'$ Θ^+ $K^0 p$	**NOMAD** Talk@neutrino 2004 Conference	$\nu C \rightarrow K^0 pX$ Θ^+ $K^0 p$
HERMES Phys. Lett. B585(2004)213	$\gamma^* d \rightarrow K^0 pX$ Θ^+ $K^0 p$	**NA49** PRL 92(2004) 042003	$pp \rightarrow \Xi \pi X$ Ξ_5
ZEUS Phys. Lett. B591(2004)7	$ep \rightarrow PX$ Θ^+ $K^0 p$	**H1** Phys. Lett. B588(2004)17	$ep \rightarrow PX$ Θ_c
COSY Phys. Lett. B595(2004)127	$pp \rightarrow K^0 p\Sigma^+$ Θ^+ $K^0 p$	**STAR** hep-ex/0406032	N_5 Ξ^0_5
		GRAAL Talk@penta2004 Conf	N_5

Θ^+ : Mass & Width



Mass

- Ranges from ≈1520 to ≈1555 MeV/c

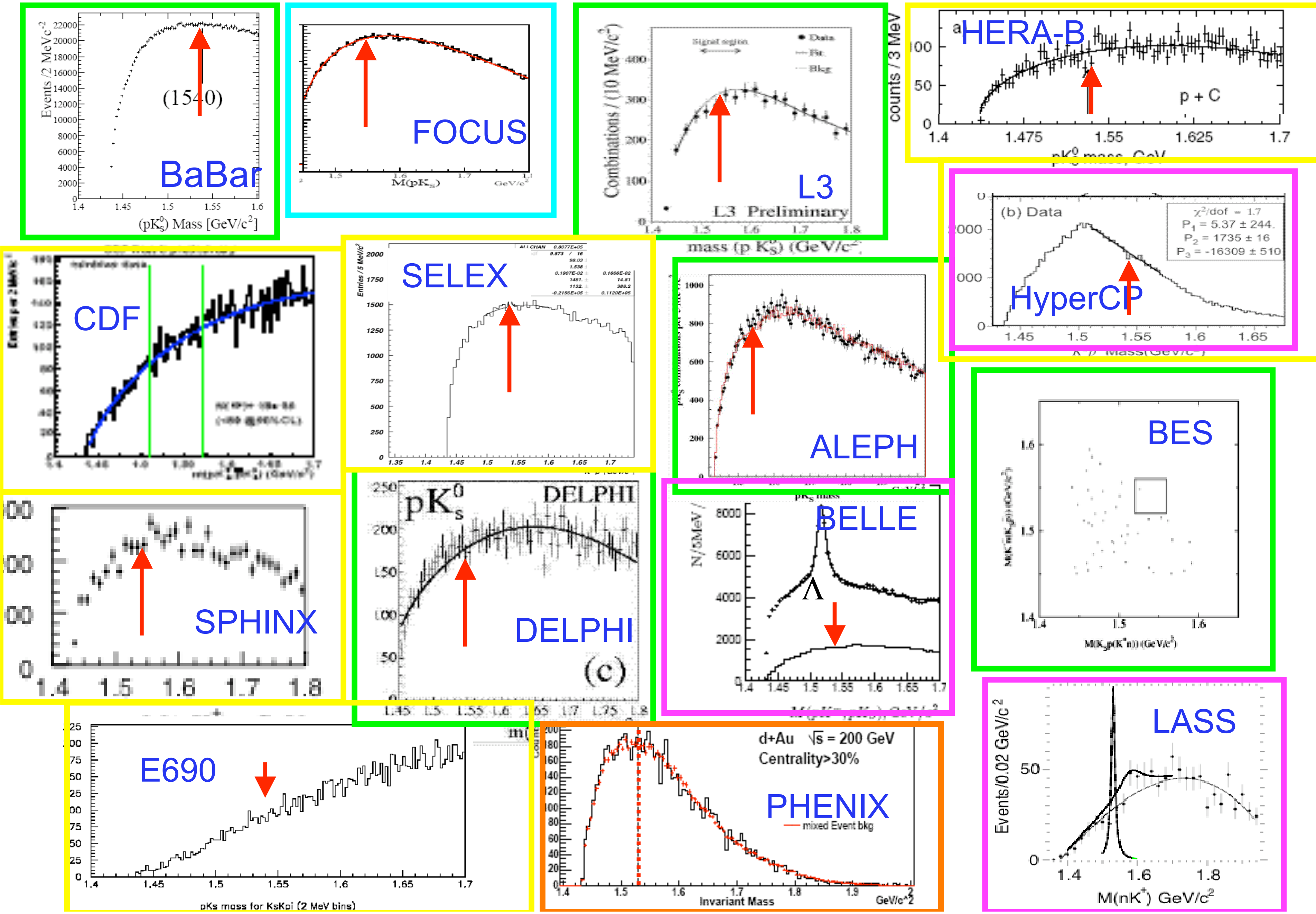
World average: 1532.2 ± 1.3 MeV/c

- Systematic shift in the ϑ^+ mass for the 2 decay modes: nK+ and pK0

Width

- FWHM ranges from ≈10 to ≈25 MeV/c dominated by experimental resolution
- Most measurements are only upper limits
- Arndt *et al.* and Cahn *et al.* analysis of KN phase shifts suggests that Γ < 1 MeV !!

Null Θ^+ States



Negative Results

CDF hep-ex/0408025 hep-ex/0410024	ppbar $\rightarrow$ PX Θ^+ Θ_c Ξ_5	**ALEPH** Phys. Lett. B599(2004)1	Hadronic Z decays Θ^+ Θ_c Ξ_5
HyperCP PRD 70 (2004) 111101	$(\pi^+,K^+,p)Cu \rightarrow PX$ Θ^+	**DELPHI** hep-ex/0410080	Hadronic Z decays Θ^+
SELEX Quark Confinement 2004	$(\pi,p,\Sigma)p \rightarrow PX$ Θ^+	**L3** hep-ex/0410080	$\gamma\gamma \rightarrow \Theta\Theta$bar Θ^+
FOCUS hep-ex/0412021	$\gamma p \rightarrow PX$ Θ^+ Θ_c Ξ_5	**WA89** PRC 70 (2004) 022201	$\Sigma^- N \rightarrow PX$ Ξ_5
E690 Quark Confinement 2004	pp $\rightarrow$ PX Θ^+ Ξ_5	**ZEUS** hep-ex/0410029/0412005 hep-ex/0412014	ep $\rightarrow$ PX Θ_c Ξ_5
BES PRD 70 (2004) 012004	$e^+e^- \rightarrow J/\psi(\psi(2S))$ Θ^+	**HERA-B** PRL 93(2003) 212003	pA $\rightarrow$ PX Θ^+ Ξ_5
BELLE hep-ex/0411005	KN $\rightarrow$ PX Θ^+ Θ_c	**SPHINX** Eur. Phys. J. A21(2004) 455	pC(N) $\rightarrow$ ΘKC(N) Θ^+
BaBar hep-ex/0408064	$e^+e^- \rightarrow \Upsilon(4S)$ Θ^+ Ξ_5	**PHENIX** nuc-ex/0404001	AuAu $\rightarrow$ PX Θ^+

Comments on positive and null results

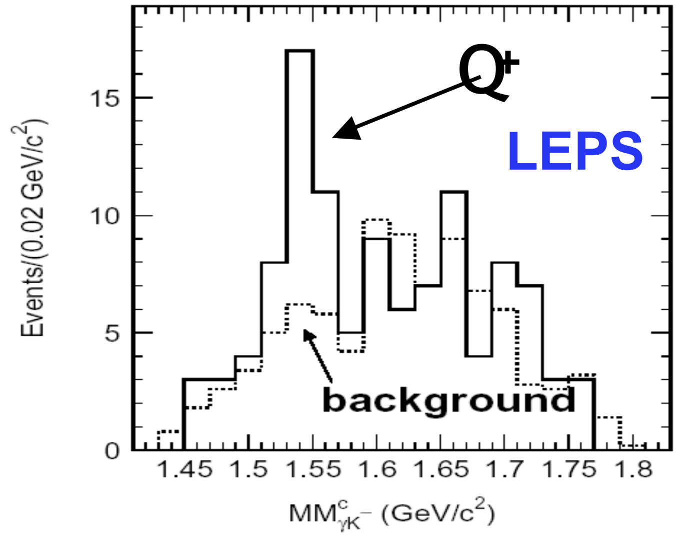
There are **valid criticisms** for both positive and null experimental results

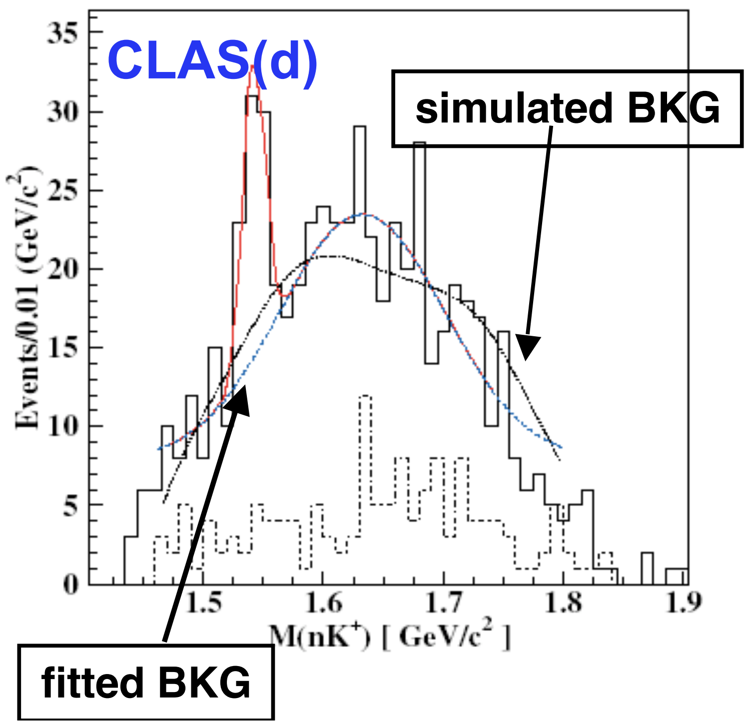
Critical View on Positive Experiments

- For most of the experiments, the background shape is not clearly known
- Some experiments have harsh cuts that could affect the spectra unexpectedly
  or specific reaction mechanism are assumed
  cuts are necessary to lower the background
- Kinematic Reflections?
- Almost all experiments have less than 100 signal events (except ZEUS)

Background

Background due to the non-resonant K^+K^- production in the region above 1.59 GeV fitted by a distribution of events from LH_2 target and scaled by a factor 0.2





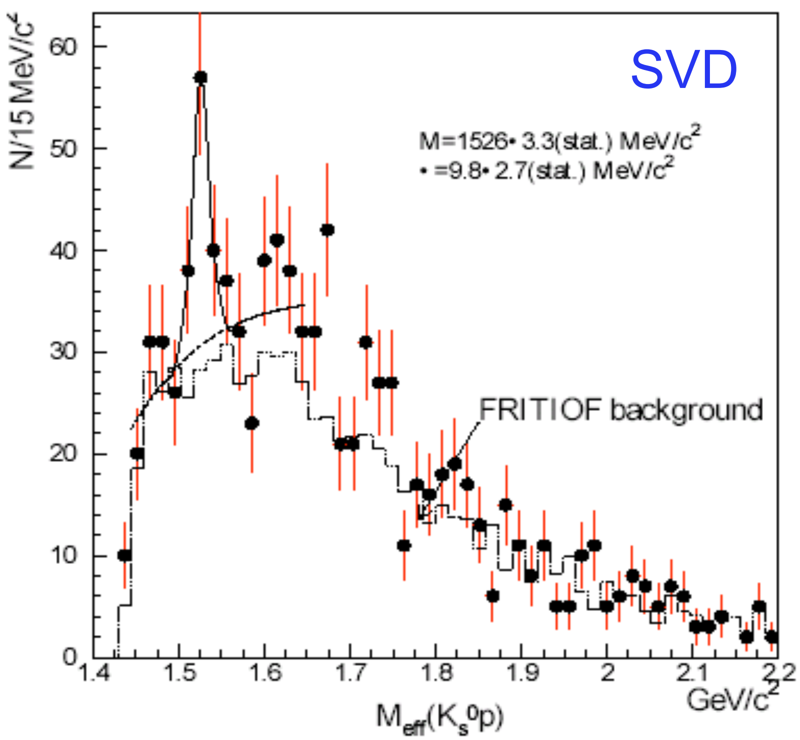
Monte Carlo calculation

- three (pK^+K^-) and four-body (pK^+K^-n) phase-space photoproduction
- full simulation of detector response
- BKG spectrum fitted to the data

Using Monte Carlo calculation: σ=4.8

Using different fitting functions: σ=4.6÷5.8

Background



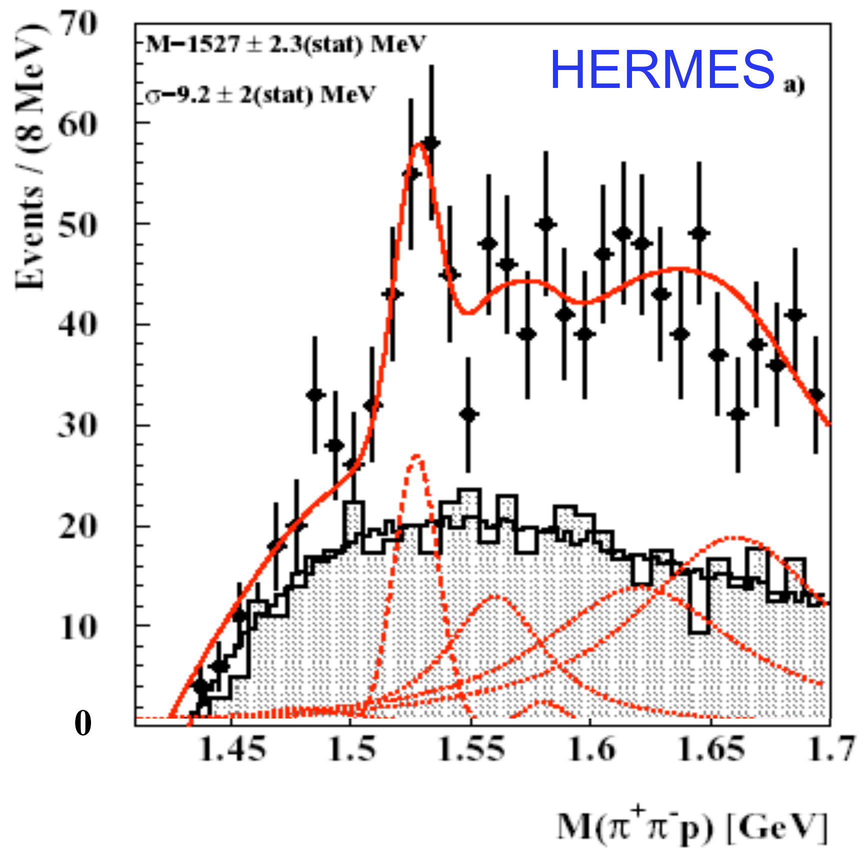
FRITIOF (hadron-hadron, hadron-nucleus interactions generator) fails to reproduce the real background shape. This may be caused by the bunch of Σ^{*+} bumps which have rather high branching ratio for pK^0 decays.

Distribution fitted by Gaussian function and a fourth-order polynomial background.

Background

Monte Carlo calculation:

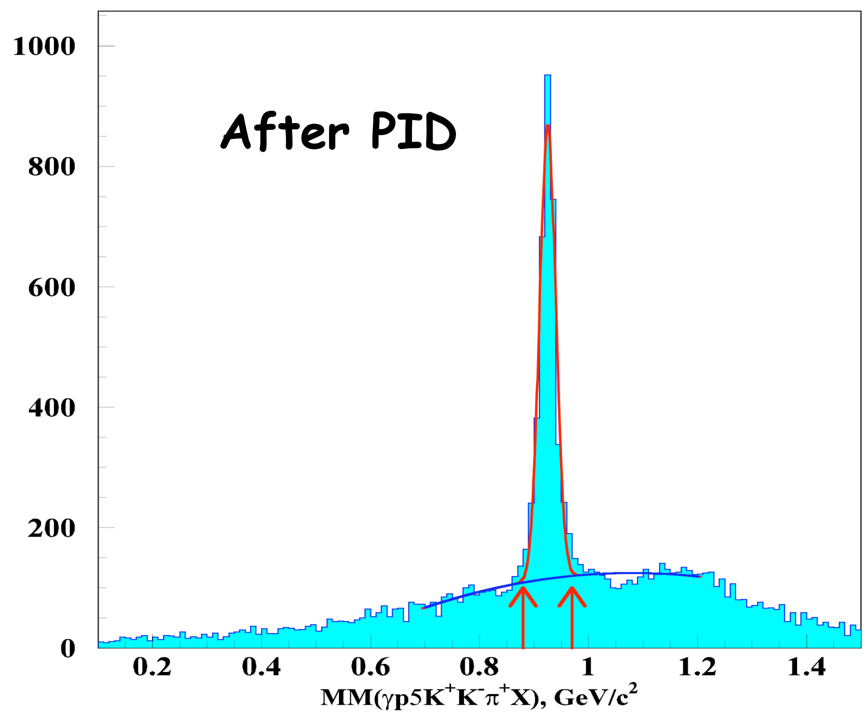
- **non-resonant contribution from PYTHIA code**
- **six S^{+*} broad resonances decaying into K^0p**
- **one narrow resonance near 1.53 GeV**
- **Quite good description of the spectrum**

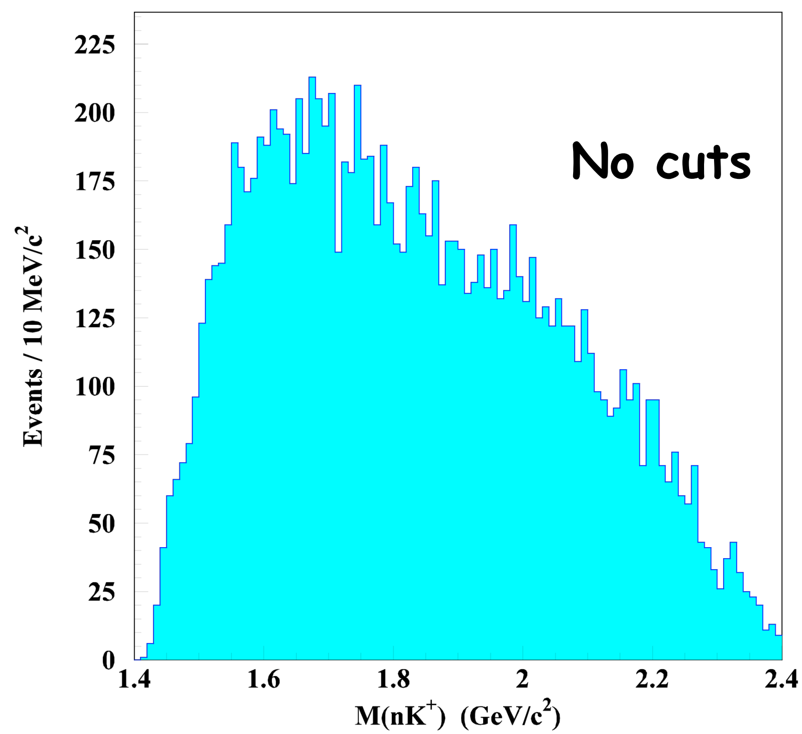


CLAS - Exclusive Production on Hydrogen (I)

gp → p+ K- Q+
→ n K+

- Data taken in 1999 and 2000 runs
- Tagged photons 3.0 < Eg < 5.25

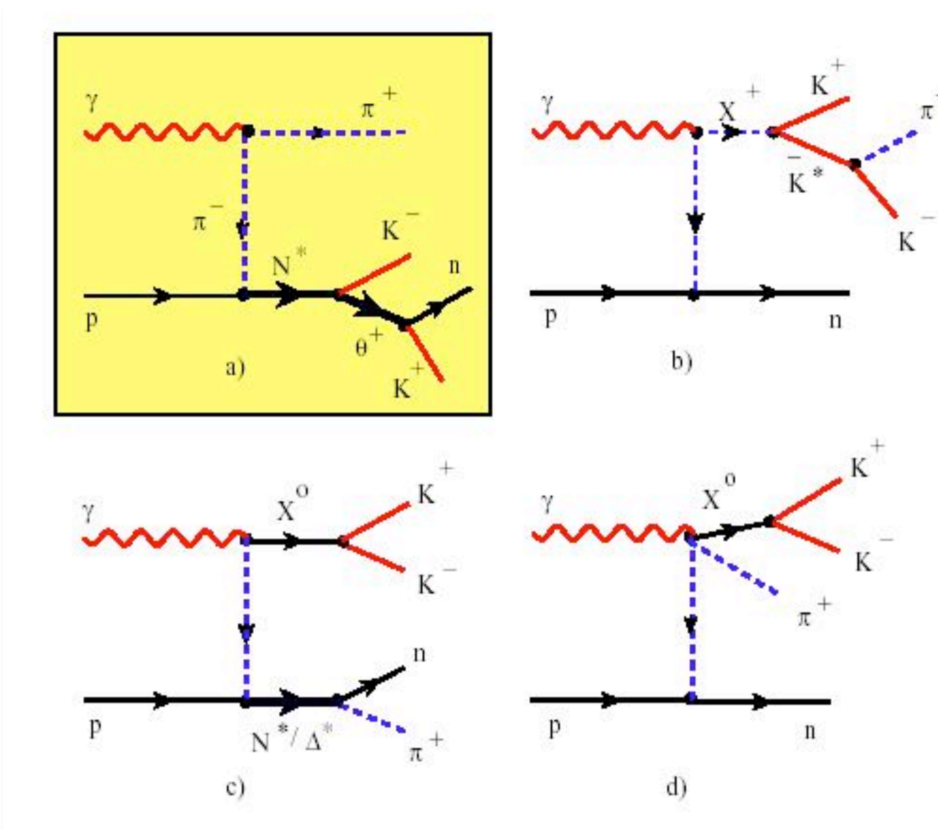




Further cuts are motivated by assumptions on production mechanism

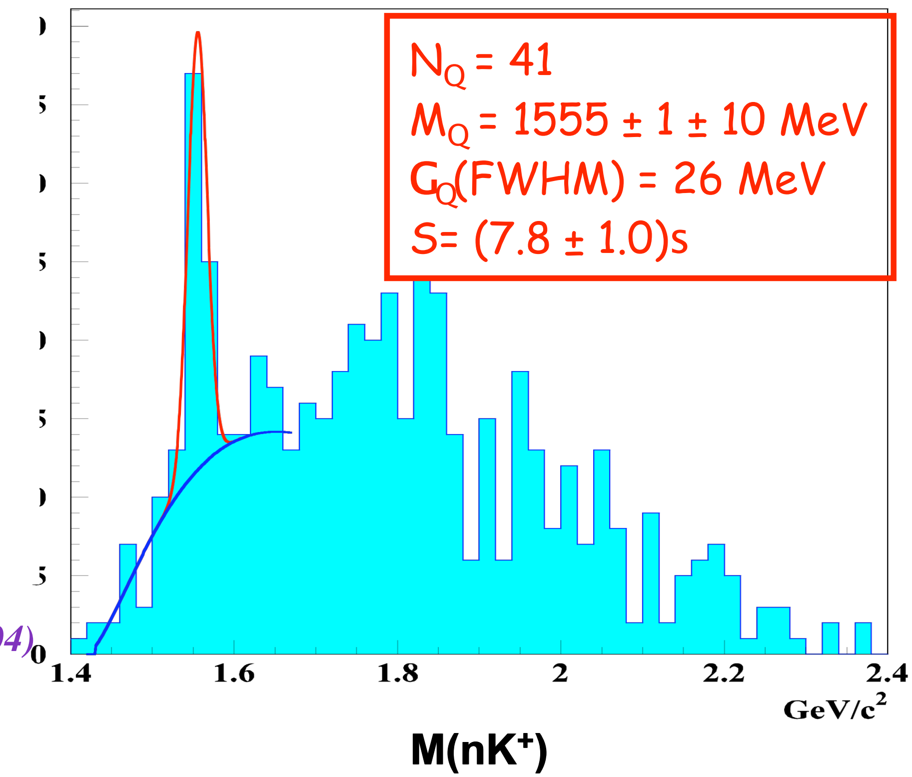
CLAS - Exclusive Production on Hydrogen (II)

Possible production mechanism



•Select t-channel process by tagging forward p+ and reducing K- from t-channel processes

cos ϑ* p+ >0.8
cos ϑ* K+ <0.6
(in c.m. frame)



PRL 92, 032001-1 (2004)

CLAS - Exclusive Production from Deuterium

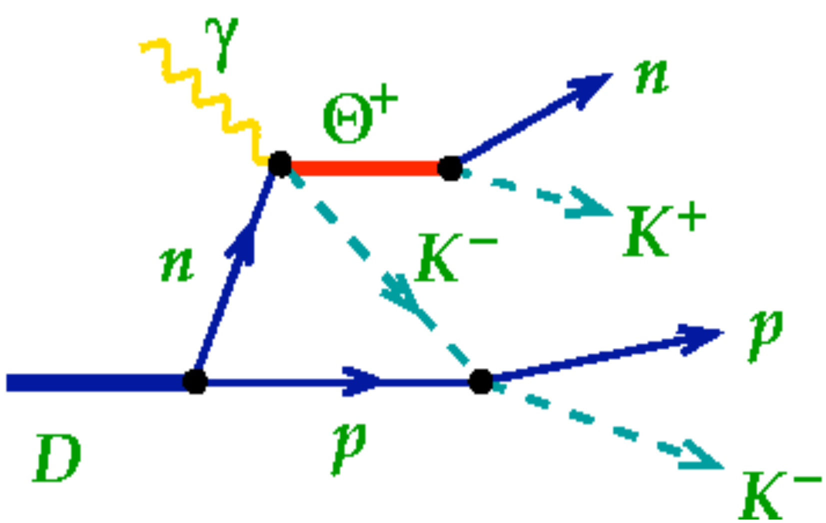
$gd \rightarrow p\ K^-\ Q^+$

$\rightarrow n\ K^+$

First **exclusive** measurement

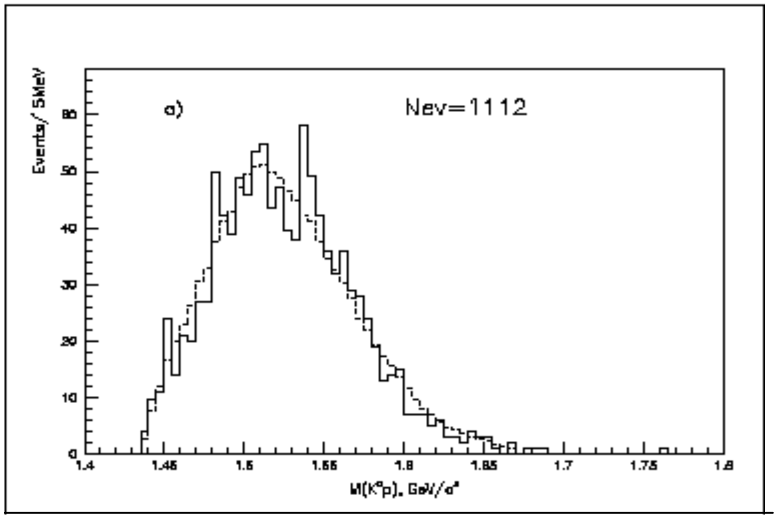
- Data taken in 1999 run
- Tagged photons with up to 3 GeV
- Charged particle detected in CLAS
- Neutron ID by missing mass

Possible reaction mechanism



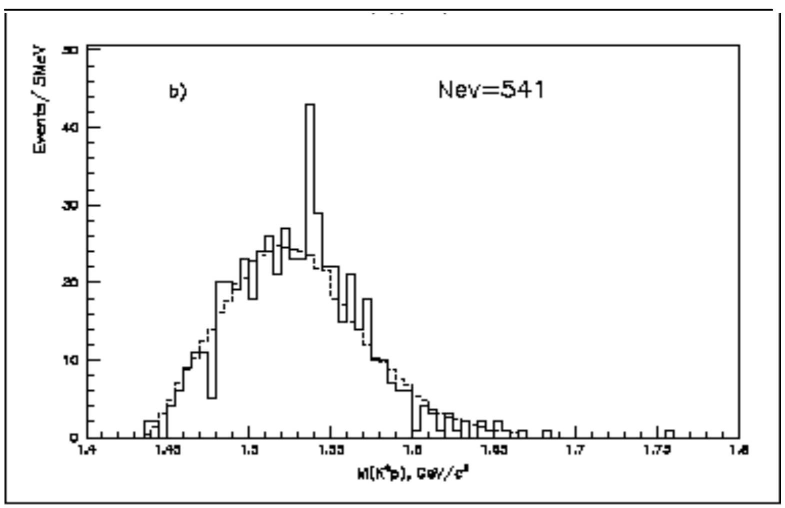
Requires FSI
both nucleons involved

DIANA



Inv mass(K^0_sp) without cuts to reduce rescattering

$$\boxed{\frac{s}{\sqrt{b}} = 2.6\sigma}$$



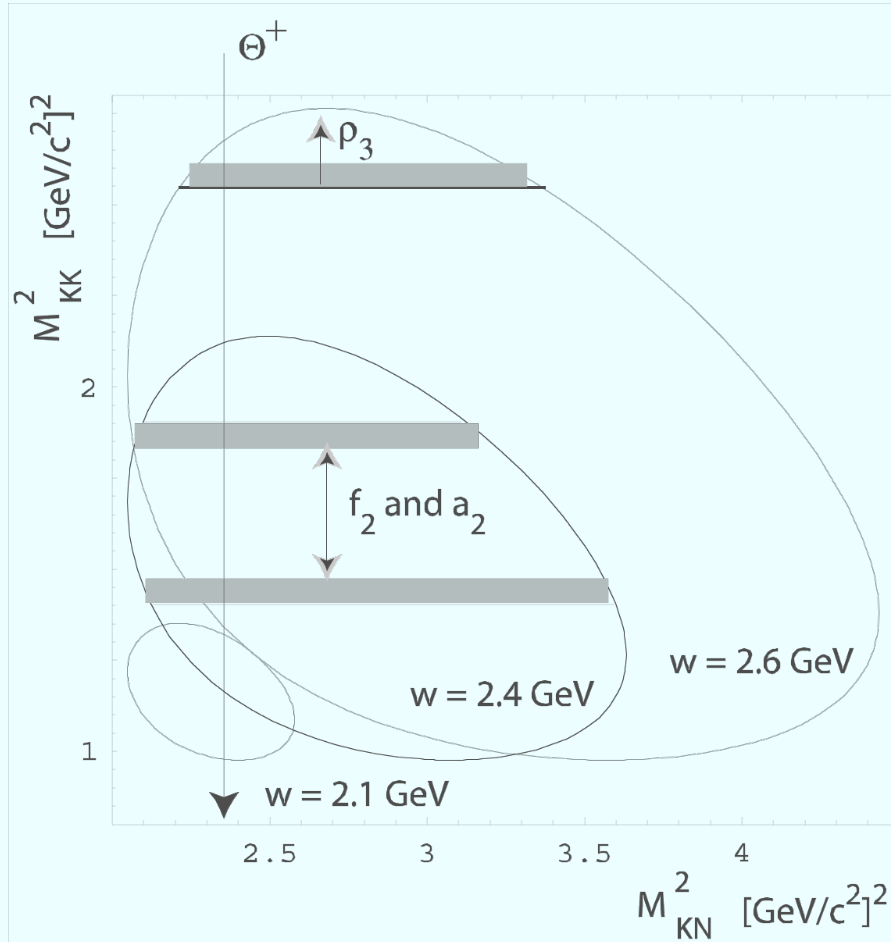
Inv mass(K^0_s p) with cuts to reduce rescattering

- θ_p, θ_K<100°
- cos Φ_{pK} < 0 (K^0_s and p back to back in the plane transverse to the beam direction)

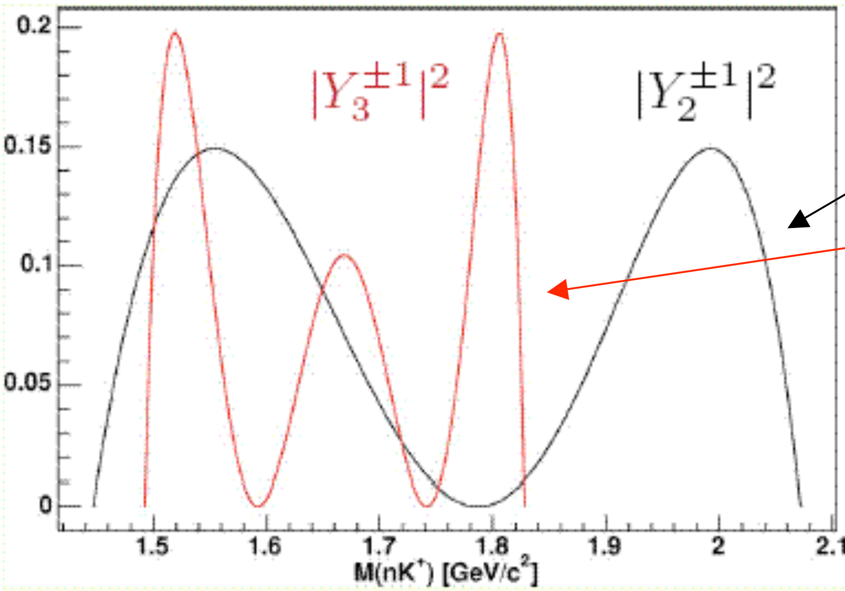
$$\boxed{\frac{s}{\sqrt{b}} = \frac{29}{\sqrt{44}} = 4.4\sigma}$$

Kinematic Reflections

High mass mesons
$a_2(1320)$, $f_2(1270)$
decaying to **K^+K^-**
can produce
structures in M(NK)
at low mass
(A. Dzierba et al., hep-ph/0311125)

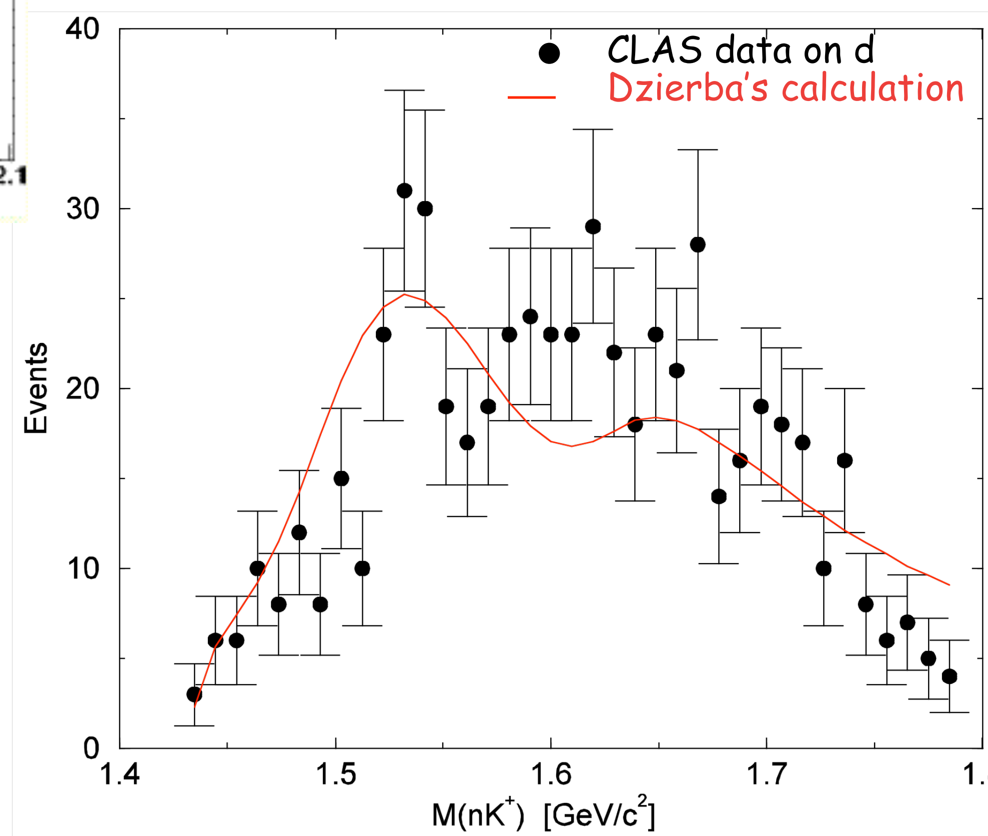


Kinematic Reflections



$m_{KK} = m(a_2)$ & $|Y_2^{\pm 1}(\vartheta,\phi)|^2$

$m_{KK} = m(\rho_3)$ & $|Y_3^{\pm 1}(\vartheta,\phi)|^2$



K. Hicks et al., hep-ph/0411265 found inconsistencies in Dzierba's approach

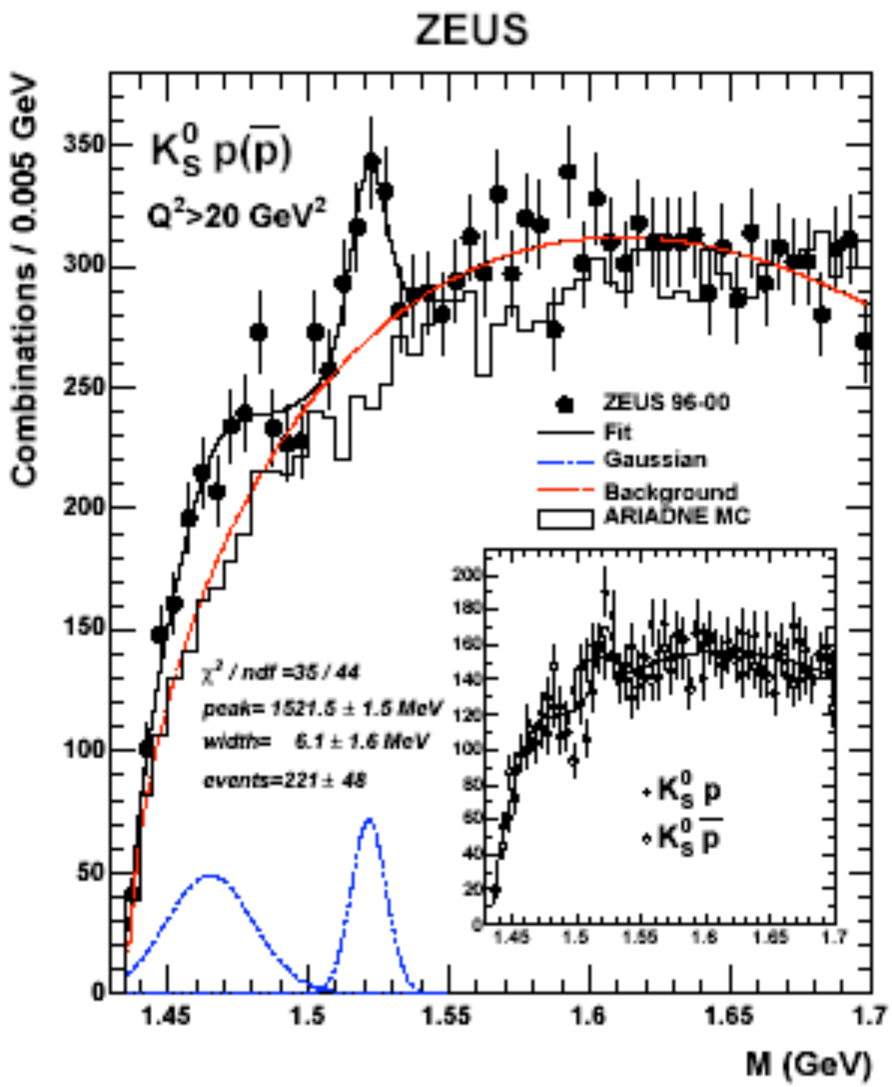
Signals Statistical Significance

$$\xi_1 = \frac{s}{\sqrt{b}}$$

$$\xi_2 = \frac{s}{\sqrt{s+b}}$$

Experiments	Signal s	Background b	Published	Significance ξ_1	Significance ξ_2
LEPS	19	17	4.6	4.6	3.2
DIANA	29	44	4.4	4.4	3.4
CLAS(d)	43	54	5.2	5.9	4.4
CLAS(p)	41	28	7.8	7.8	4.9
SAPHIR	55	56	4.8	7.3	5.2
COSY	60	103	4-6	5.9	4.7
SVD	50	78	5.5	5.6	4.4
νBC	19	8	6.7	6.7	3.7
HERMES	52	155	4.3-6.2	4.2	3.6
ZEUS	230	1080	4.6	7.0	6.4
NOMAD	33	59	4.3	4.3	3.4

Results from ZEUS



Phys. Lett. B591(2004)7

1. Q^+ peak is evident only for Q^2 > 20 GeV^2.
→ZEUS suggests that this condition gives the Q^+ enough transverse momentum to get into their detector acceptance.

2. Background
→MC simulation using ARIADNE gen. does not describe well data <1.6 GeV
The PDG reports a Σ bump at 1480 MeV and several states above 1550 MeV.
None of these are included in the simulation which includes only well established resonances
Background fit with a 3-par function + 2 gaussian

Critical View on Negative Experiments

- All negative results are from high energy experiments: inclusive versus exclusive measurement
  - -inclusive has better resolution but more background
- Production mechanisms are not generally known
  - -sensitivity to the pentaquarks may be highly suppressed in the current fragmentation

Negative Results for Θ^+ in $e^+ e^-$

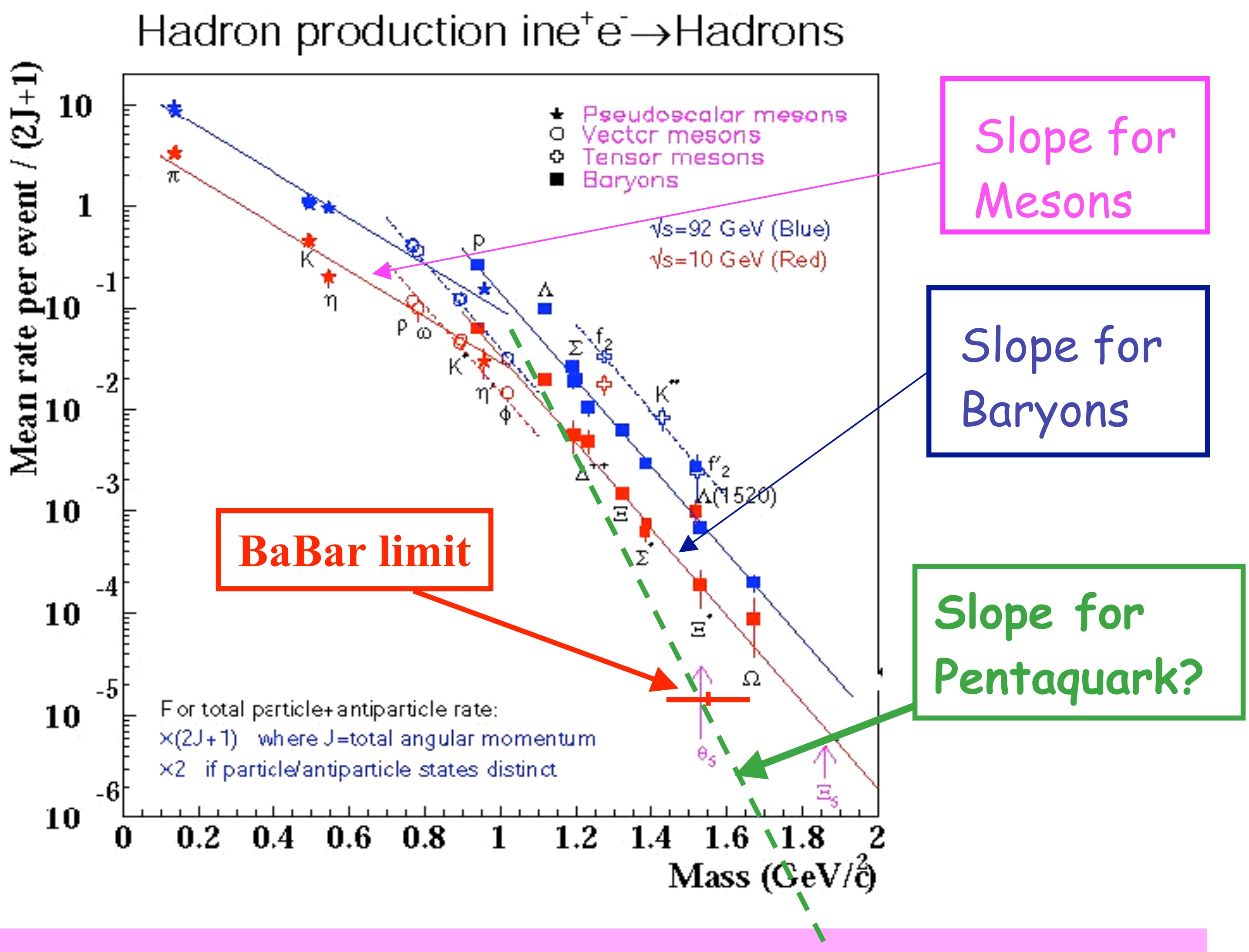
Exp	$\sqrt{s}$(GeV)	Reaction	Statistics	Upper Limit
BES	3.7	$e^+e^- \to \psi(2S) \to \Theta\bar{\Theta}$ J/ψ	14×10^6 58×10^6	$J/\psi \to \Theta\bar{\Theta} \to K^0pK^-\bar{n} + K^0\bar{p}K^+n < 1.1 \times 10^{-5}$ $\psi(2S) \to \Theta\bar{\Theta} \to K^0pK^-\bar{n} + K^0\bar{p}K^+n < 0.84 \times 10^{-5}$ $\psi(2S)$ - $J/\psi \to$ single Θ pro. $< \sim 10^{-5}$
BaBar	10.5	$e^+e^- \to \Upsilon(4S) \to B\bar{B}$	135×10^6	$e^+e^- \to q\bar{q} \to \Theta X < 5\text{-}10 \times 10^{-5}$
ALEPH	~91	$e^+e^- \to Z^0 \to q\bar{q} \to \Theta X$	4×10^6	$e^+e^- \to Z^0 \to \Theta X < 0.6 \times 10^{-5}$

BES

PRD 70 (2004) 012004

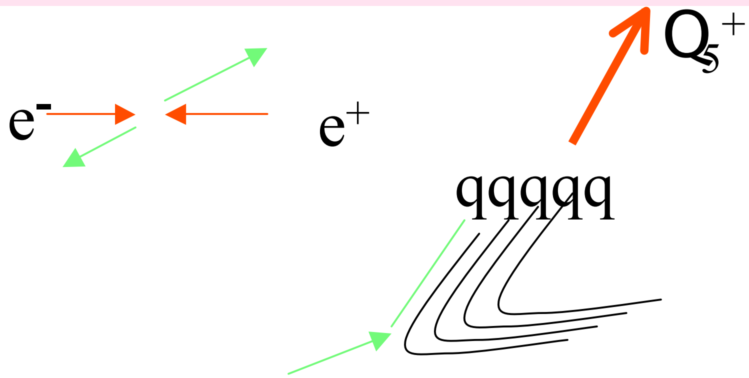
non-observation of the pentaquark state $\Theta(1540)$ here does not mean it does not exist. It is generally believed that the dominant mechanism for charmonium ($\psi(2S)$ and J/ψ) decays is that they annihilate through three gluons. If each gluon produces one $q\bar{q}$ pair, it is natural for $\psi(2S)$ or J/ψ to decay into three $q\bar{q}$ pairs, which could form, for example, ordinary baryon-antibaryon states. For pentaquark production, five gluons are needed to produce five $q\bar{q}$ pairs. Hence its production rate in $\psi(2S)$ or J/ψ decay is expected to be small. Our result is compatible with this expectation.

Hadron Rate in e^+e^-



e^+e^- experiments may be not sensitive to pentaquark signal

Hadron Rate in e^+e^-



Current fragmentation

Θ^+ = baryon containing a strange antiquark

a) Low energy photoproduction experiment :

baryon (target) - strange antiquark (strange component of the γ)

b) e+e- experiments

B number and S must be created from gluons

How to normalize Θ^+ production in b) with respect to a) ?

Measuring B-$\bar{\text{B}}$ and Y-$\bar{\text{Y}}$ in the same exp that does not see the Θ^+

Tuning: measure the ratio $\bar{d}/\bar{p}$ in a given experiment

$\bar{d}/\bar{p}$ (H1) = $5.0 \pm 1.0 \pm 0.5 \times 10^{-4}$

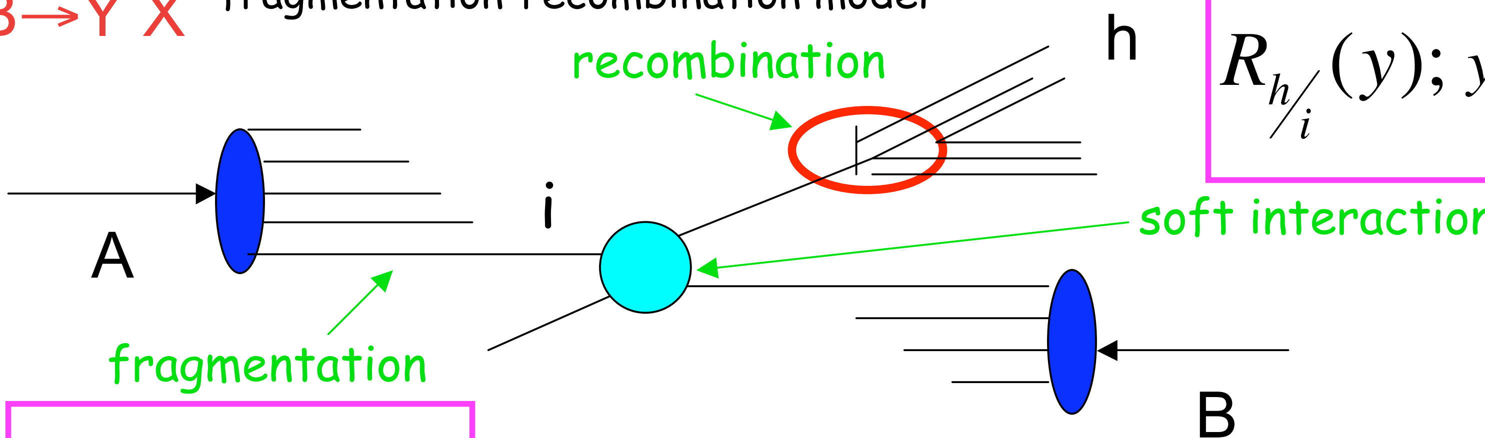
$\bar{d}/\bar{p}$ (OPAL) = 0.8×10^{-5} (90% C.L.)

Inclusive Production (fragmentation region)

A B→Θ⁺X
A B→Y X

X-section estimation on the base of fragmentation-recombination model

Titov et al. nucl-th/0408001



$$R_{h/i}(y);\ y = \frac{p_h}{p_i}$$

$$F_{i/A}(x);\ x = \frac{p_i}{p_A}$$

$$\sigma \propto \int F_{i/A}(x) R_{h/i}(y) \delta(z - xy)\, dx\, dy;\ z = \frac{p_h}{p_A}$$

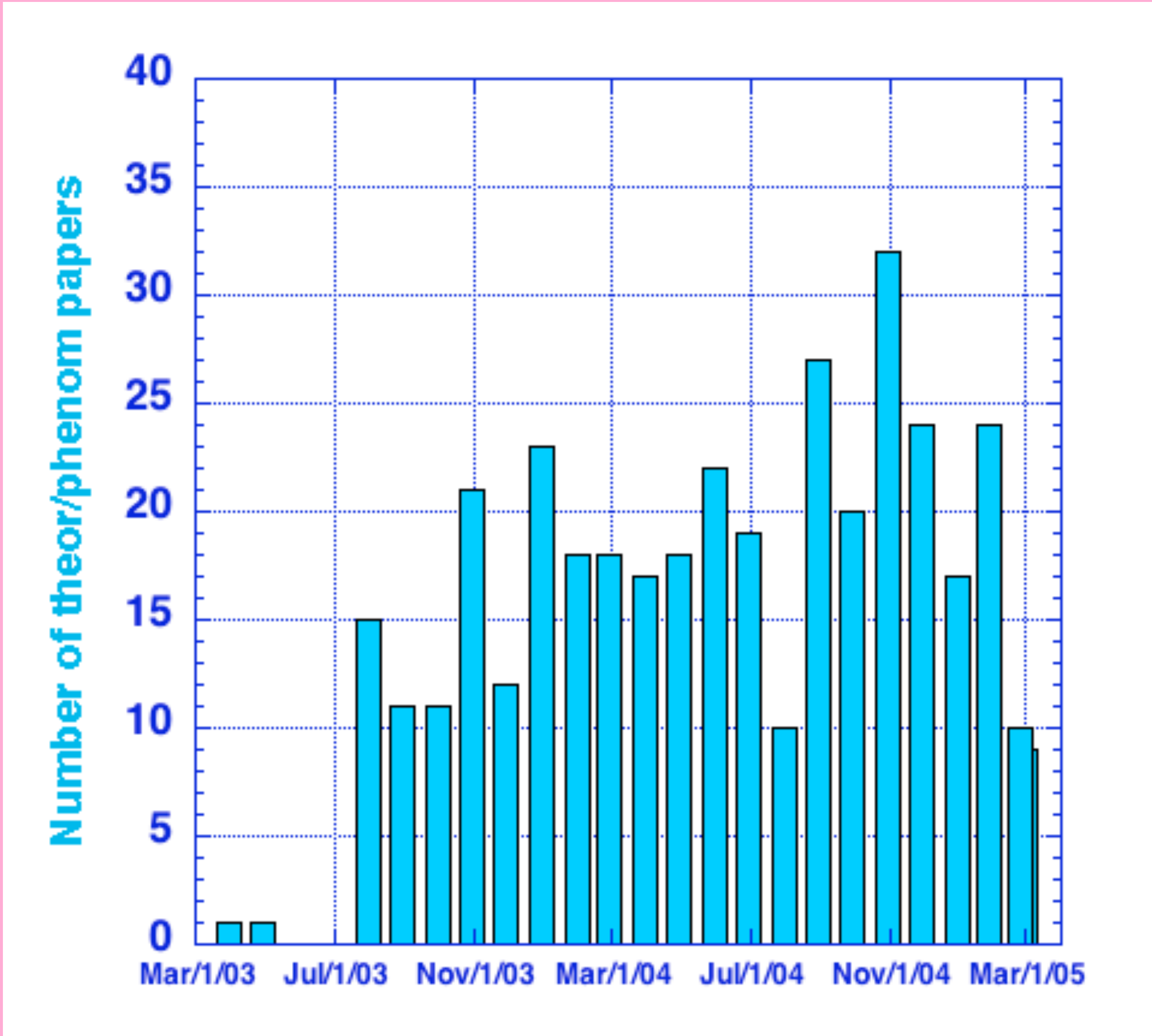
Scale behavior of F & R $\quad F_{i/A}(x) = F_0(x)(1-x)^{b_A^i} \quad R_{h/i}(y) = R_0(y)(1-y)^{c_i^h}$

F_0 and R_0 smooth function of x and y ; keeping the dominant term the ∫ can be performed by an elementary method; z = 0.7 typical value for the fragm region

$$R_{\Theta Y} \sim \begin{cases} 0.11(1-z)^4 & \text{[quarks]} \\ 0.30(1-z)^2 & \text{[diquarks]} \end{cases} \qquad R_{\Theta Y} \sim \begin{cases} 9 \times 10^{-4} & \text{[quark]} \\ 3 \times 10^{-2} & \text{[diquark]} \end{cases}$$

HERA-B	$pA \to pK_s^0 X$	$< 0.02\ L(1520)$
CDF	$p\bar{p} \to pK_s^0 X$	$< 0.03\ L(1520)$

Theoretical Development



Conclusion on the experimental review

….. $\Theta(1540)+$ PDG july 2004

It is difficult to deny a status of three stars and a place in the Summary Tables for a state that six experiments claim to have seen. Nevertheless, as discussed in the above note, we believe it reasonable to have some reservations about the existence of this state on the basis of the present evidence.

H. Lipkin hep-ph/0501209

Guidance from the wisdom of Feynman and Wigner

1. Feynman told us that we learned from sharpening contradictions
2. Wigner told us that few free parameters can fit an elephant. A few more can make him wiggle his trunk
3. Wigner's response to questions about a particular theory he did not like was:" I think that this theory is wrong. But the old Bohr - Sommerfield quantum theory was also wrong. Could we have reached the right theory without going through that stage?"

Goal of the Experimental 5-quark Program @ JLab

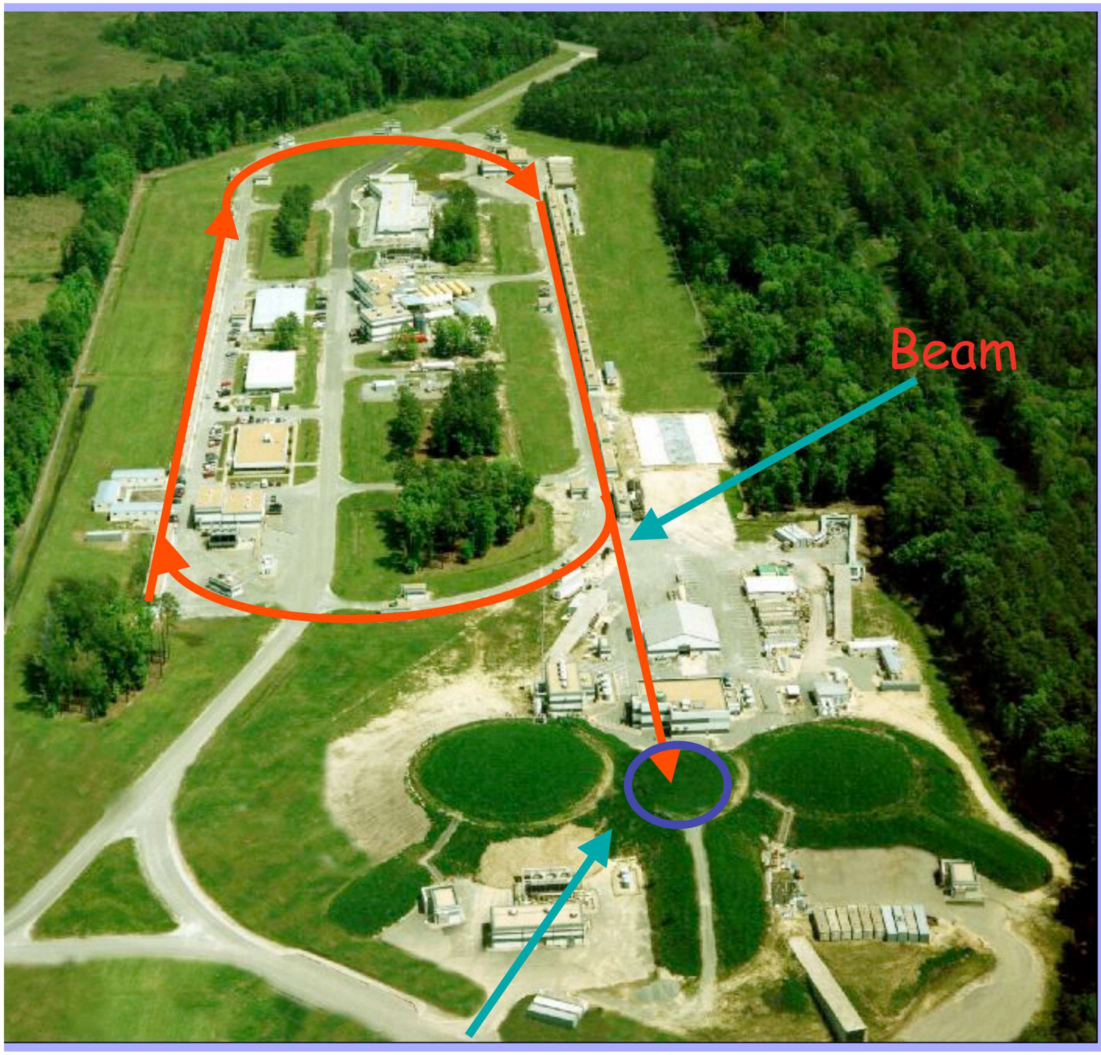
We need conclusive confirmation of the Q^+

Experiments at low energies, with much higher statistics will settle the question

Goal of the Experimental 5-quark Program @ JLab

- High statistics search for Q^+
- Solving the issues of Q^+ (1540)
- Search for excited states of the Q^+ (1540)
- Search for the other exotic members of the 10plet X_5^{--}, X_5^{+}?

JLab Accelerator CEBAF



Superconducting recirculating electron accelerator

- Continuous Electron Beam
- Energy 0.8-5.7 GeV
- 200mA, polarization 75%
- Simultaneous delivery to 3Halls

Hall B: Cebaf Large Acceptance Spectrometer + Tagger

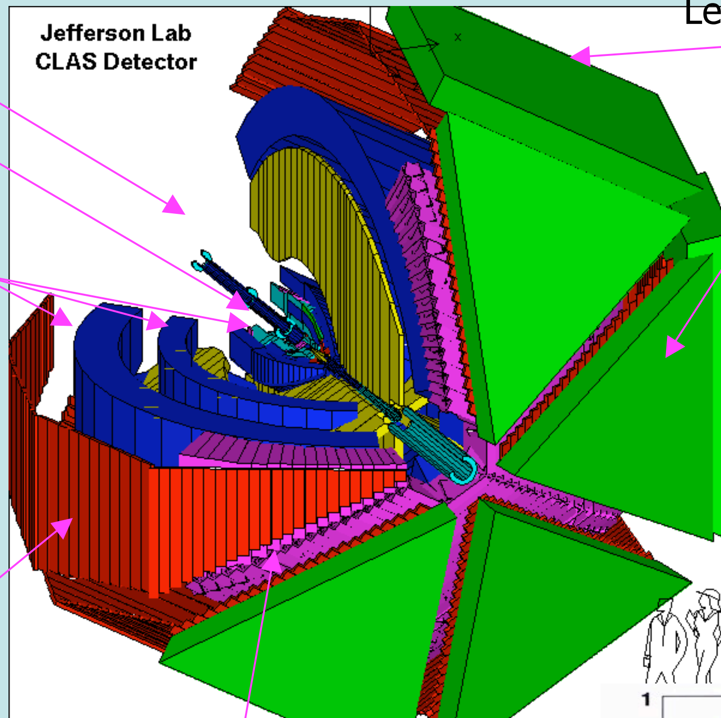
beam

Torus magnet
6 superconducting coils

Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

Liquid D_2 (H_2)target +
g start counter; e minitorus

Drift chambers
argon/CO_2 gas, 35,000 cells



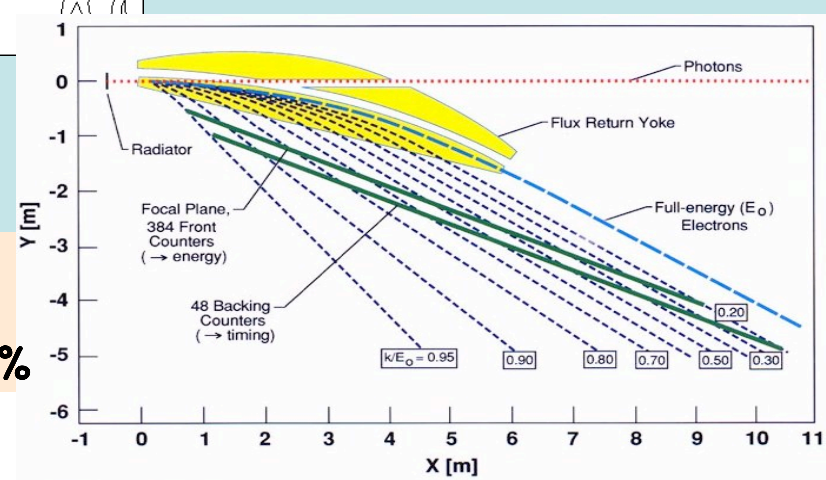
- Broad angular coverage (8° ÷ 140° in LAB frame)
- Charged particle momentum resolution ~0.5% forward dir

CLAS is designed to measure exclusive reactions with multi-particle final states

Time-of-flight counters
plastic scintillators, 684 photomultipliers

Gas Cherenkov counters
e/p separation, 256 PMTs

- E_g = (20% - 95%) E_e
- Tagged photon beam with energy resolution dk/k ~ 0.1%



Current Projects @ Jlab

JLab/Hall A (E-04-012)	Q^{++} S^0_5	ep ep	May 22 - June 1 2004	E_e : 1.5-5.4
JLab/Hall-B (E-03-113) G10	Q^+	gd	March 13-May 16 2004	E_g : 0.8-3.6
JLab/Hall-B (E-04-021) G11	Q^+ Q^{+*} Q^{++}	gp	May 22 - July 26 2004	E_g : 1.6-3.8
JLab/Hall-B (E-04-010) EG3	Ξ_5	γd	Dec 05 2004 - January 31 2005	E_e : 5.7
JLab/Hall-B (E-04-017) SUPER-G	Ξ_5 Q^+	gp	Not yet scheduled	E_g : 1.5-5.7

G10: Search for Θ^+ on Deuterium

Data Taking

- Data taking March 13 - May 16, 2004
- E_γ = 0.8 - 3.59 GeV
- B field = 2 settings of the torus magnet
  - I = 2250A : Total of 316 runs, 6015 files
    Increased acceptance for forward going negative particles
    for inclusive (K+K-) and (K_Sp) analysis
  - I = 3375A : Total of 300 runs, 6496 files
    Similar geometrical acceptance and single track resolution as
    for the published data
- Target = 24 cm liquid deuterium
- 10 billion of events collected ~ 50 pb^{-1} (10x statistic publ. results)

G10: Search for Θ^+ on Deuterium

Data Processing Status

End of January 2005: final data processing $\longrightarrow$ bos files and ntuples with 4-vectors ready for physics analysis

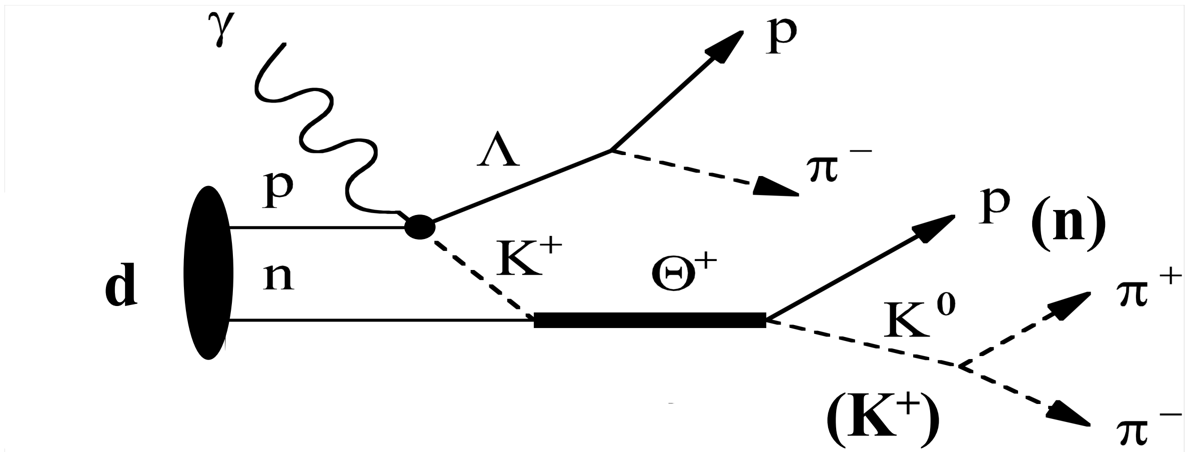
- Physics analysis tools:
  - Analysis programs – mostly ready;
  - Development of GEANT based simulation tools are in progress.

- Independent analysis of several reactions by different groups

Reactions to study

$\gamma d \rightarrow n K^+ K^- p$	$\Theta^+ \rightarrow n K^+$	
$\gamma d \rightarrow p K^0 K^- (p)$	$\Theta^+ \rightarrow p K^0$	$K^0 \rightarrow \pi^+ \pi^-$
$\gamma d \rightarrow \Lambda K^+ n$	$\Theta^+ \rightarrow n K^+$	$\Lambda \rightarrow p \pi^-$
$\gamma d \rightarrow \Lambda K^0 p$	$\Theta^+ \rightarrow p K^0$	$\Lambda \rightarrow p \pi^-$ $K^0 \rightarrow \pi^+ \pi^-$

$\gamma\, d \to \Theta^+ \Lambda$



Decay modes: $\Theta^+ \to K^0 p$ $\Lambda \to p\pi^-$ $K^0 \to \pi^+\pi^-$
$\Theta^+ \to K^+ n$ $\Lambda \to p\pi^-$

- No possibility of kinematical reflections
  (A.R. Dzierba et al., hep-ph/0311125)
- S=+1 both for nK^+ and pK^0, thanks to Λ

G2a and G10 Comparison

$\gamma d \rightarrow pK^+K^-(n)$

G2 Data Set

E_e = 2.478 GeV (2/3 of G2a)

E_γ < 2.35 GeV

Torus Current = 3375 A

Target 10 cm LD2; center of CLAS

G10 Data Set

E_e = 3.775 GeV

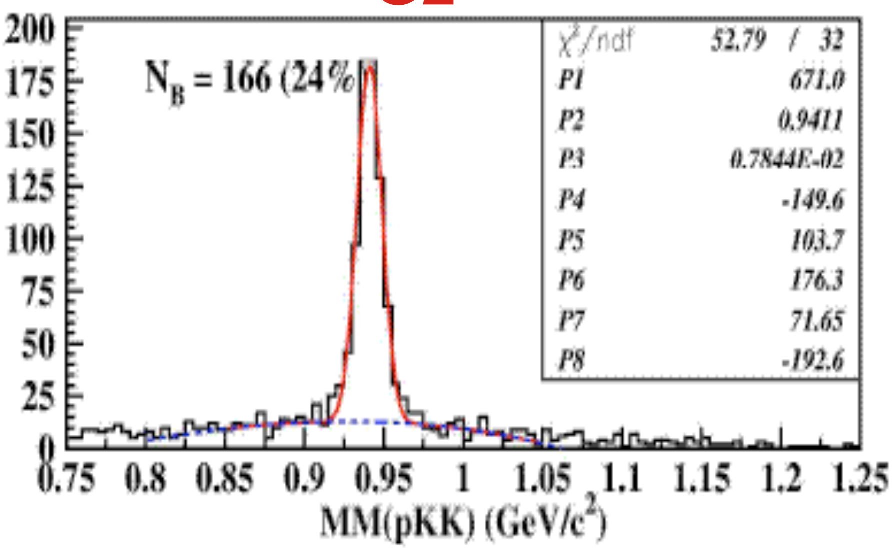
E_γ < 2.35 GeV

Torus Current = 3375 A

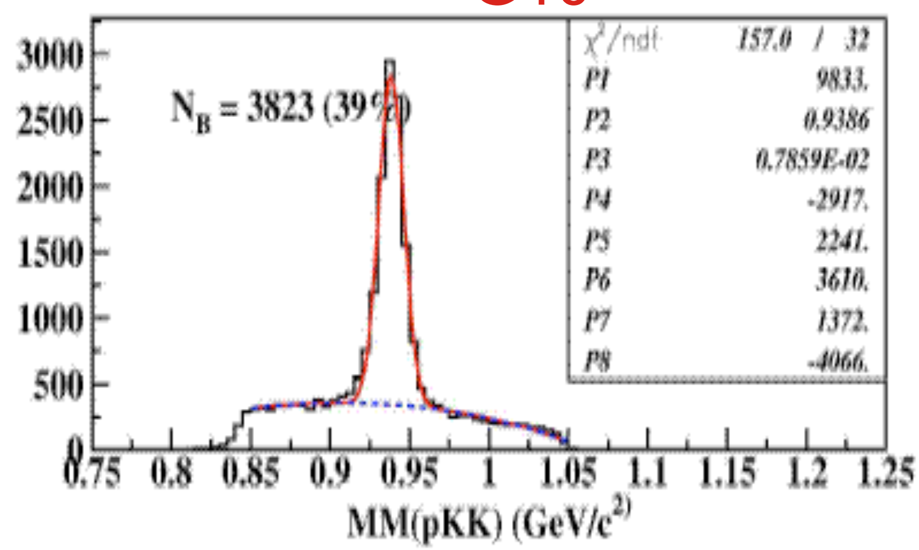
Target 24 cm LD2; -25 cm upstream of CLAS center

Missing Neutron

G2

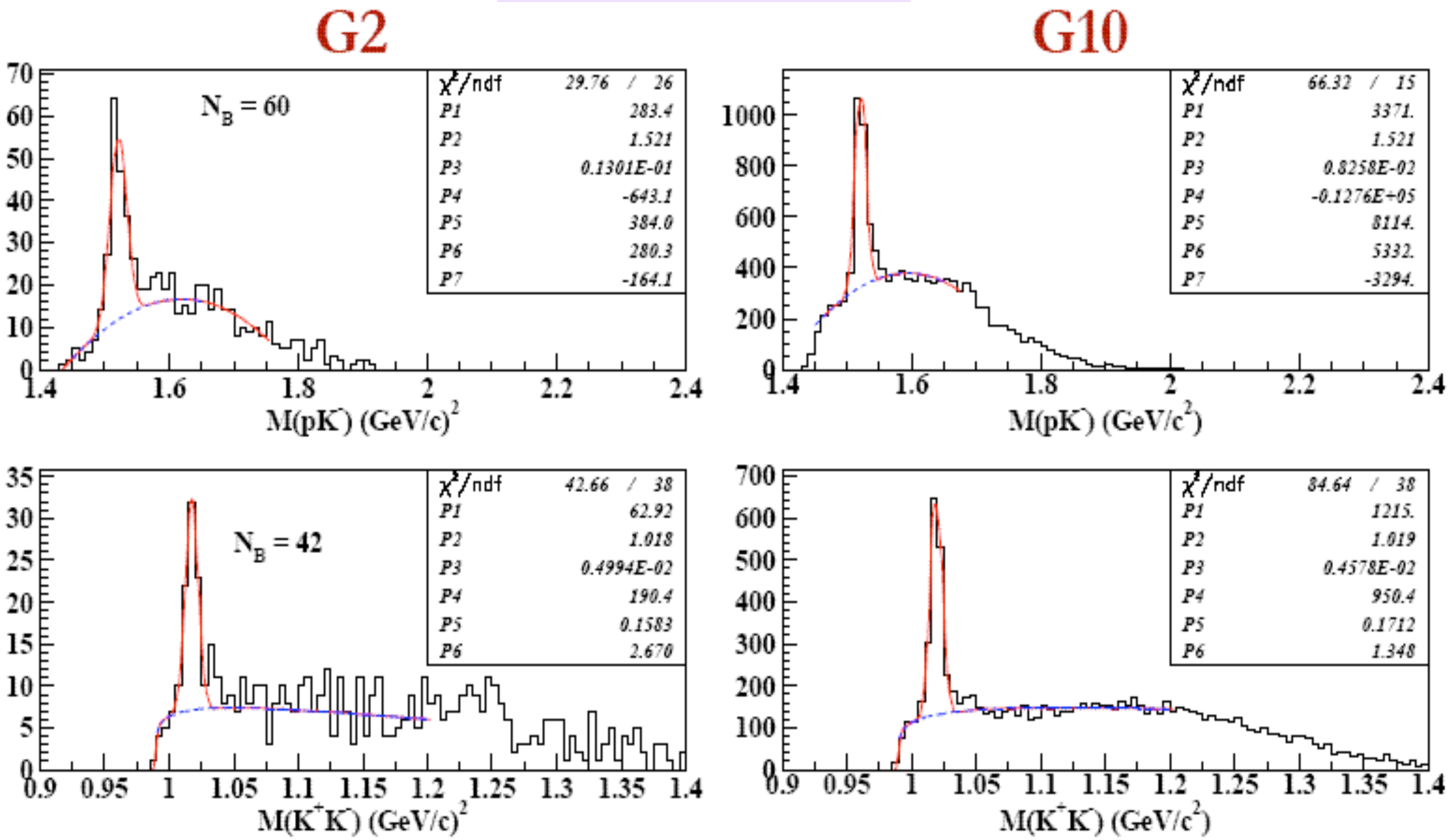


G10



G2a and G10 Comparison

Λ(1520) and φ



G11: Search for Θ^+ on Proton

Data Taking

- Data taking May 22 - July 26, 2004
- E_γ = 1.6 - 3.8 GeV
- Target = 40 cm liquid hydrogen
- Events collected ~ 80 pb^{-1} (10x statistic published results)

Data Processing Status

End of February 2005: final data processing $\longrightarrow$ bos files and ntuples with 4-vectors ready for physics analysis

Reactions to study

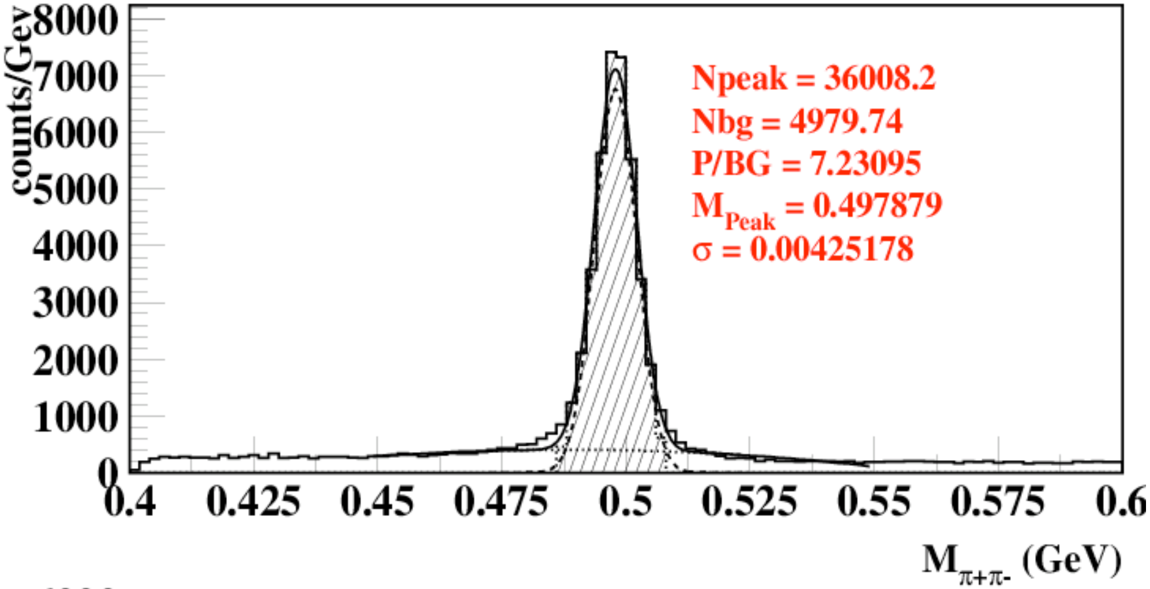
$$g+p \rightarrow Q^{+} + K^{0} \rightarrow K^{+} + n\ (K^{0} + p)\ p^{+} + p^{-}$$

$$g+p \rightarrow X^{++} + K^{-} \rightarrow K^{+} + p + K^{-}$$

$$g+p \rightarrow Q^{+} + K^{-} + p^{+} \rightarrow K^{+} + n\ (K^{0} + p) + K^{-} + p^{+}$$

G11: Search for Θ^+ on Proton

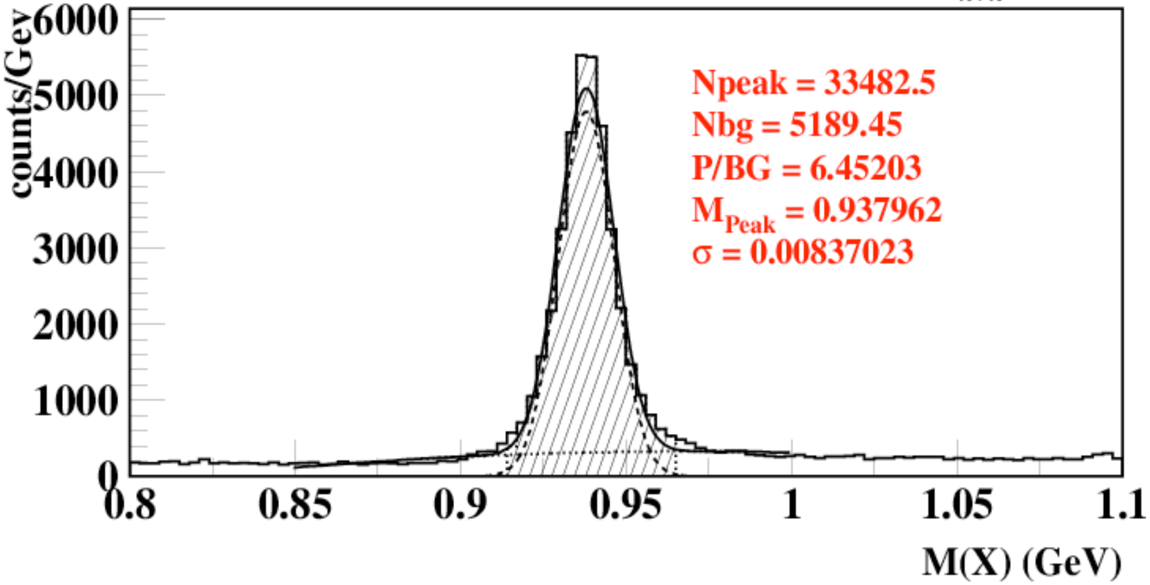
$\gamma p \rightarrow K^+ (n) \pi^+ \pi^-$



K^0

M = 497.9 MeV

σ = 4.3 MeV



n

M = 938.0 MeV

σ = 9.4 MeV

G11: Search for Θ^{+} on Proton

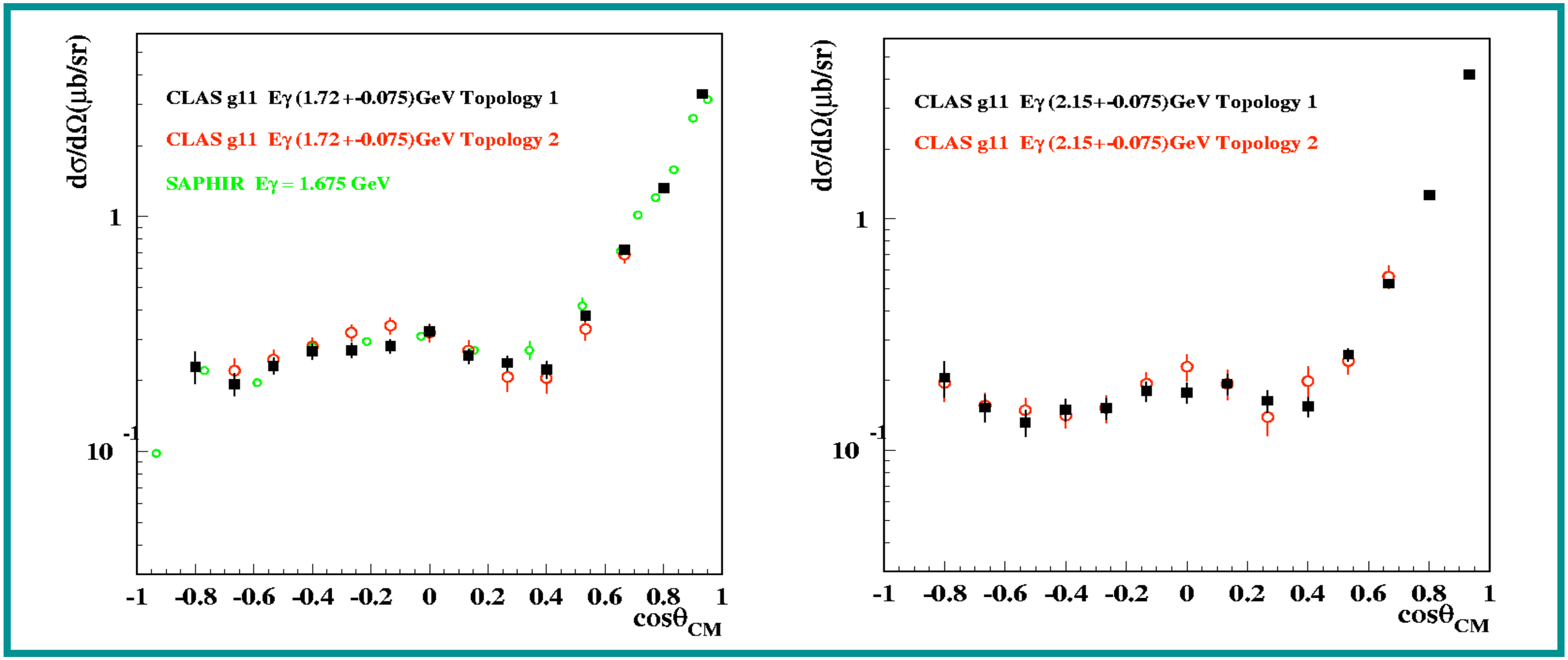
Development and test of the analysis procedure through the cross section extraction for known reactions

$\gamma p \rightarrow p\ \omega$

Differential cross section

$\rightarrow p\ p^{+} (p^{-}\ p^{0})$ **Topology 1**

$\rightarrow p\ p^{+}\ p^{-}\ (p^{0})$ **Topology 2**

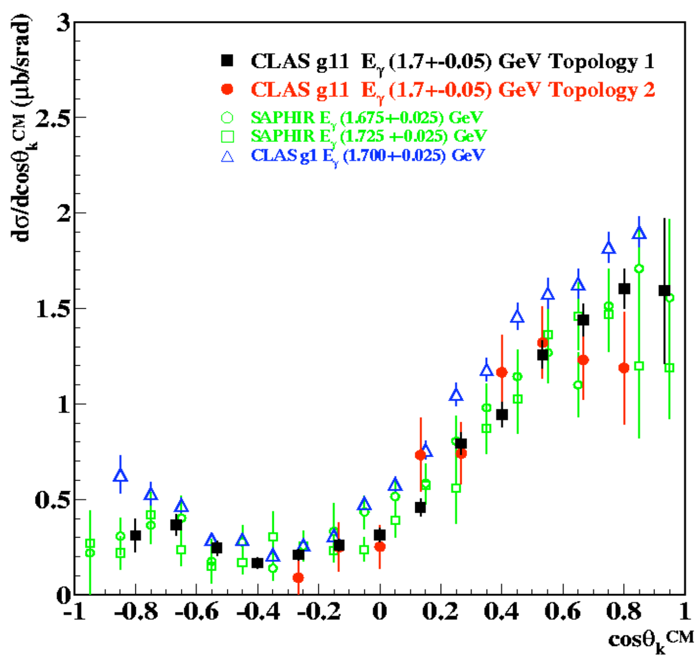


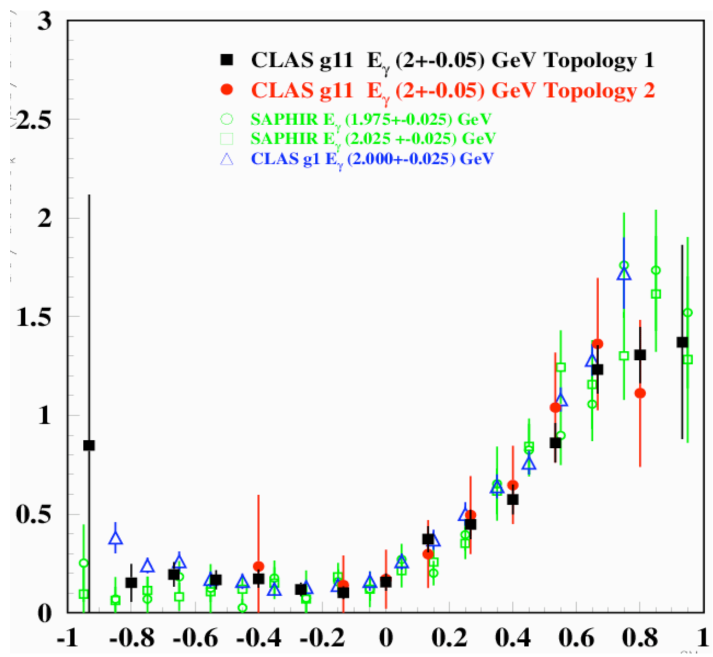
G11: Search for Θ^+ on Proton

$\gamma p \rightarrow K+ \Lambda(1116)$ Differential cross section

$\rightarrow K^+ p\ (p^-)$ Topology 1 L as MM_{K+}

$\rightarrow K^+ p\ p^-$ Topology 2 L as IM_{pp-}



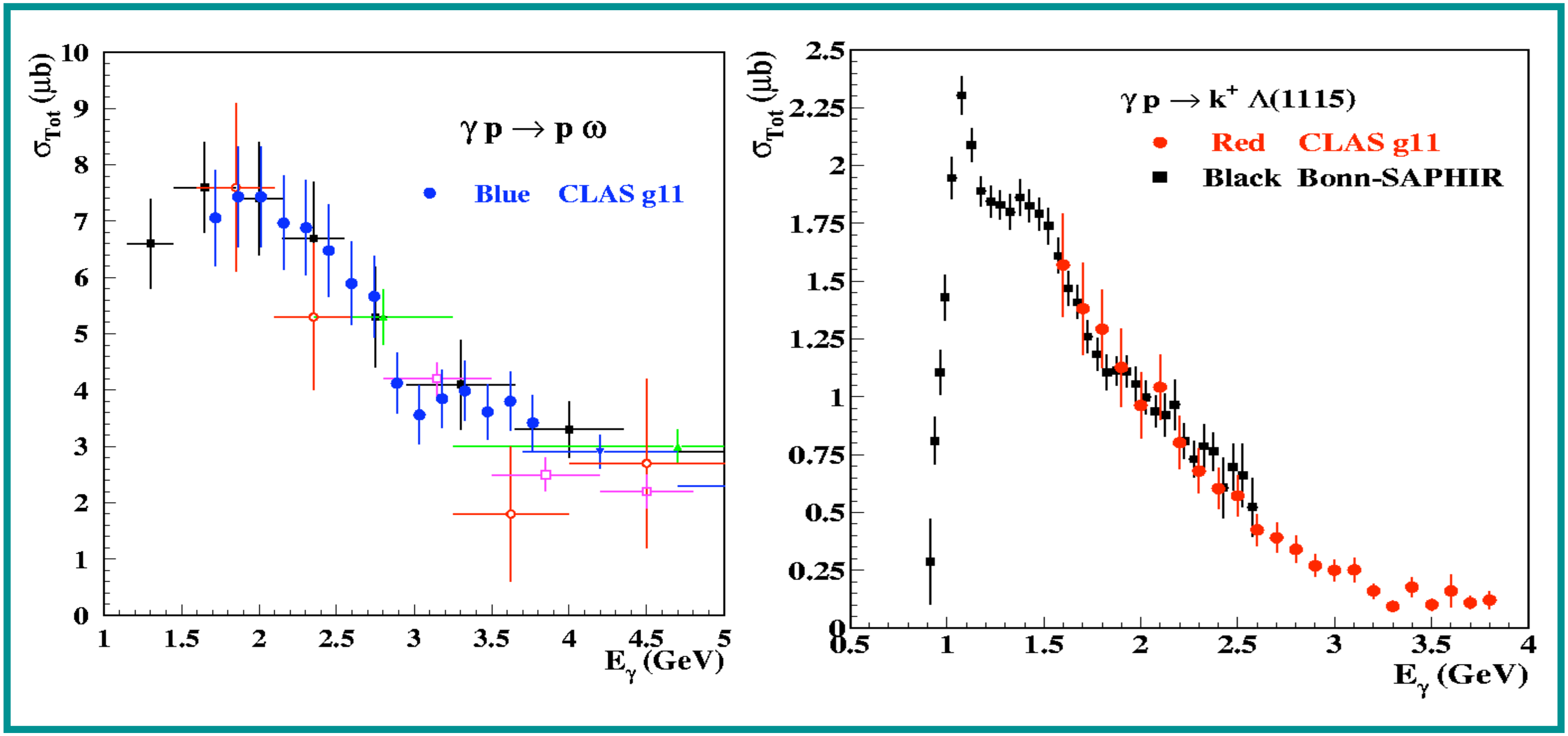


G11: Search for Θ^+ on Proton

$\gamma p \rightarrow K^+ \Lambda(1116)$

$\gamma p \rightarrow p\,\omega$

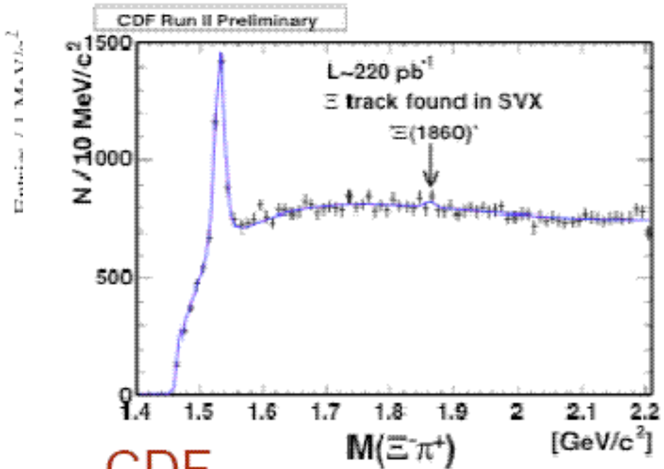
Total cross sections



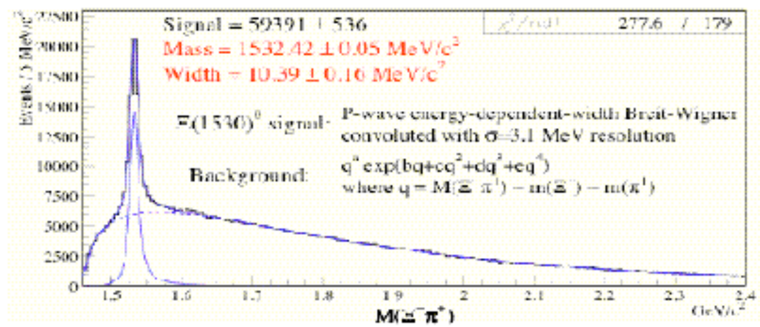
EG3: Search for Pentaquark Cascades

Null Result $\Xi_5(1860)$

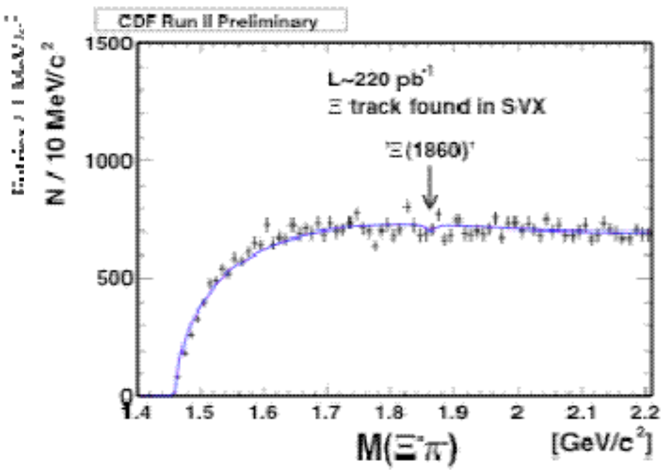
$\Xi^{--}(1862) \rightarrow \Xi^{-}\pi^{-}$
$\Xi^{0}(1862) \rightarrow \Xi^{-}\pi^{+}$



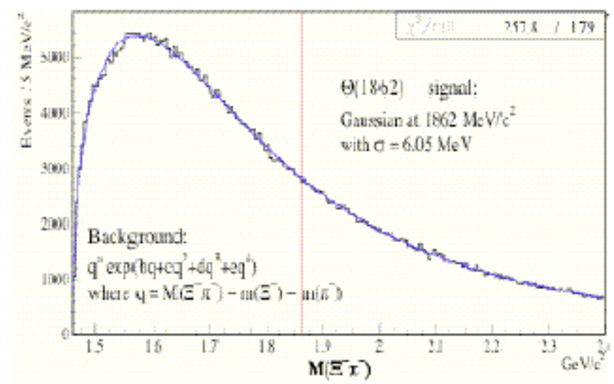
ALEPH and ZEUS also null result



CDF



FOCUS

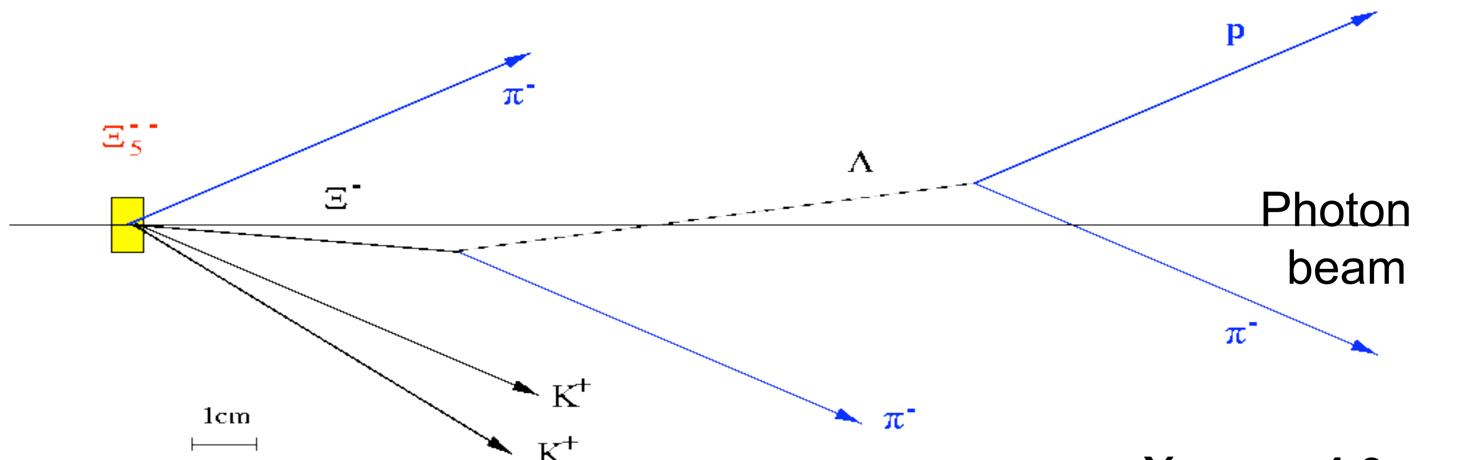


EG3: Search for Pentaquark Cascades

- CLAS allows simultaneous detection of multiple particles in the final state. In particular channel

$$
\begin{array}{lllll}
\gamma d \to & (K^+K^+p_s) & \Xi_5^{--} & \to \\
 & (K^+K^+p_s) & \pi^-\Xi^- & \to \\
 & (K^+K^+p_s) & \pi^-\pi^-\Lambda & \to \\
 & (K^+K^+p_s) & \pi^-\pi^-\pi^-p &
\end{array}
$$

can be studied with CLAS.



X– ct = 4.9 cm

L ct = 7.9 cm

Two decay vertices,

Negatives bend outwards

<gb> ~ 1.5

EG3: Search for Pentaquark Cascades

Data Taking

- Data taking Dec 5 2005- January 31, 2005
- E_γ = 4.4 - 5.5 GeV
- Target = 40 cm liquid deuterium
- Events collected ~ 4.2 Billion

Analysis Plan

Develop procedures to identify detached vertices with ~1cm resolution.

Identify Λ using ($p\pi^-$) missing mass.

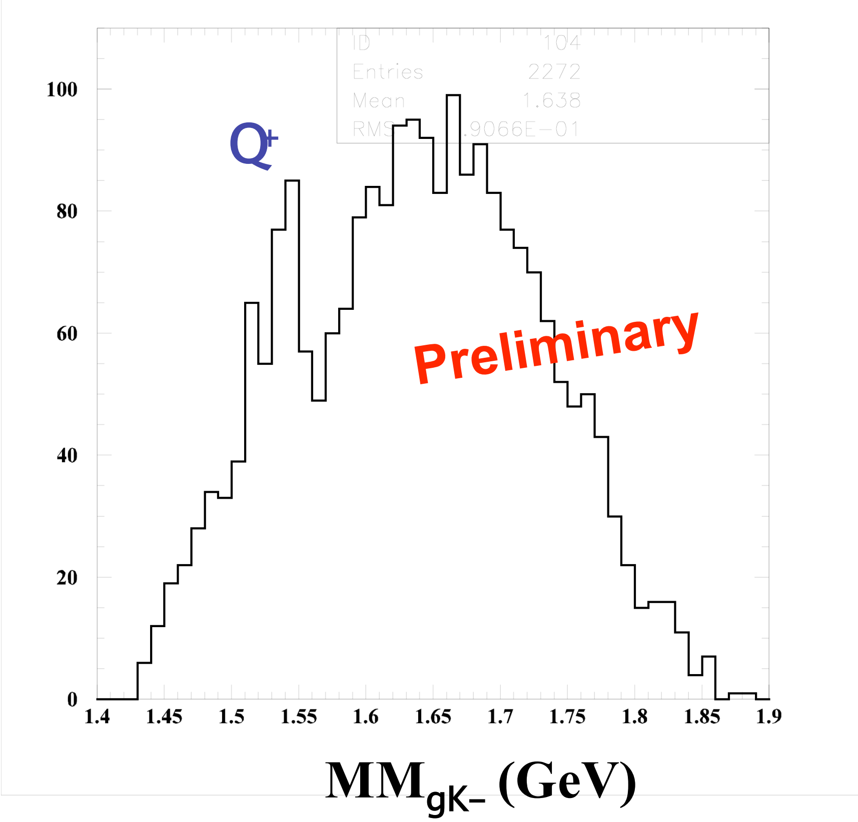
Identify Ξ^- using ($\Lambda\pi^-$) invariant mass, DOCA and flight path.

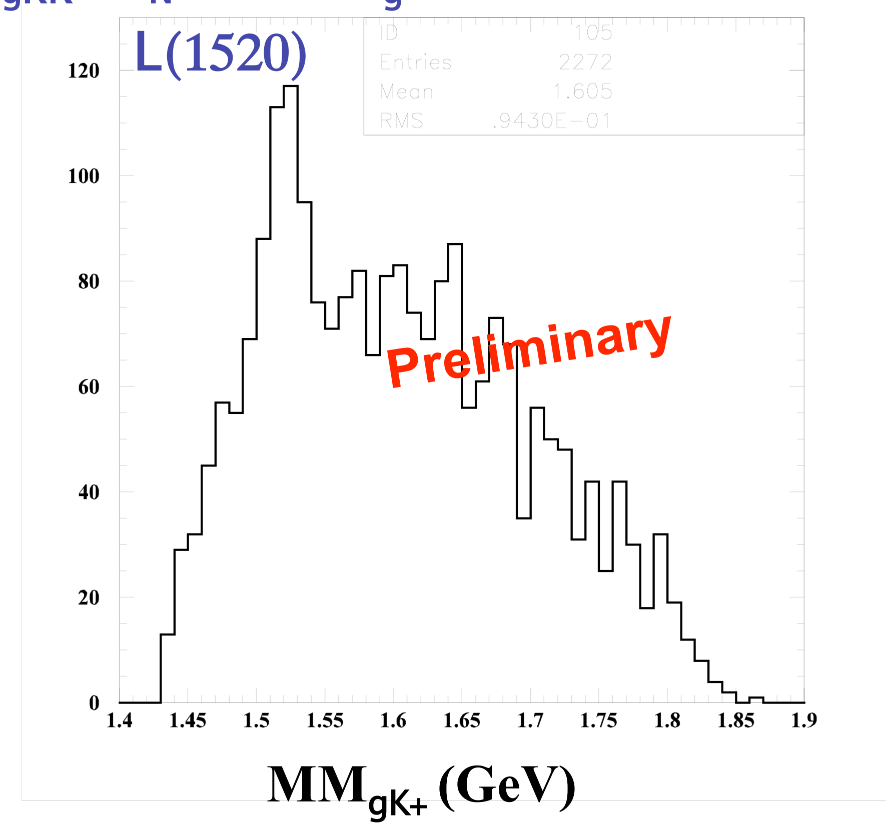
Plot invariant mass of ($\Xi^-\ \pi^-$) to find Ξ^{--} peak.

Develop/utilize kinematical fitting procedure to enhance peaks and use confidence level cuts.

New data: LEPS deuterium

Minimal cuts: vertex, $MM_{gKK}=M_N$, no f , E_g < 2.35 GeV





Hope with CLAS to give soon a final answer on the pentaquark issue