

The Experimental Search for Pentaquarks: Overview and Perspectives

S. Niccolai, IPN Orsay

(for the CLAS Collaboration)

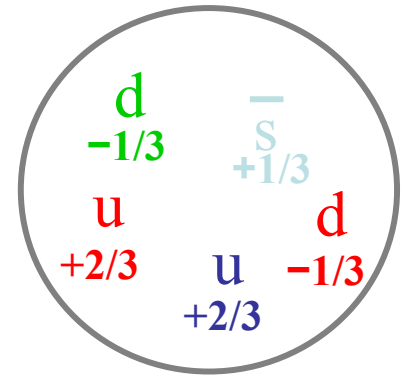
- Introduction
- Published experimental results
- CLAS analyses in progress
- Negative results
- Pentaquark program at CLAS
- Outlook

QCD04

Montpellier 5/7/2004

What are pentaquarks?

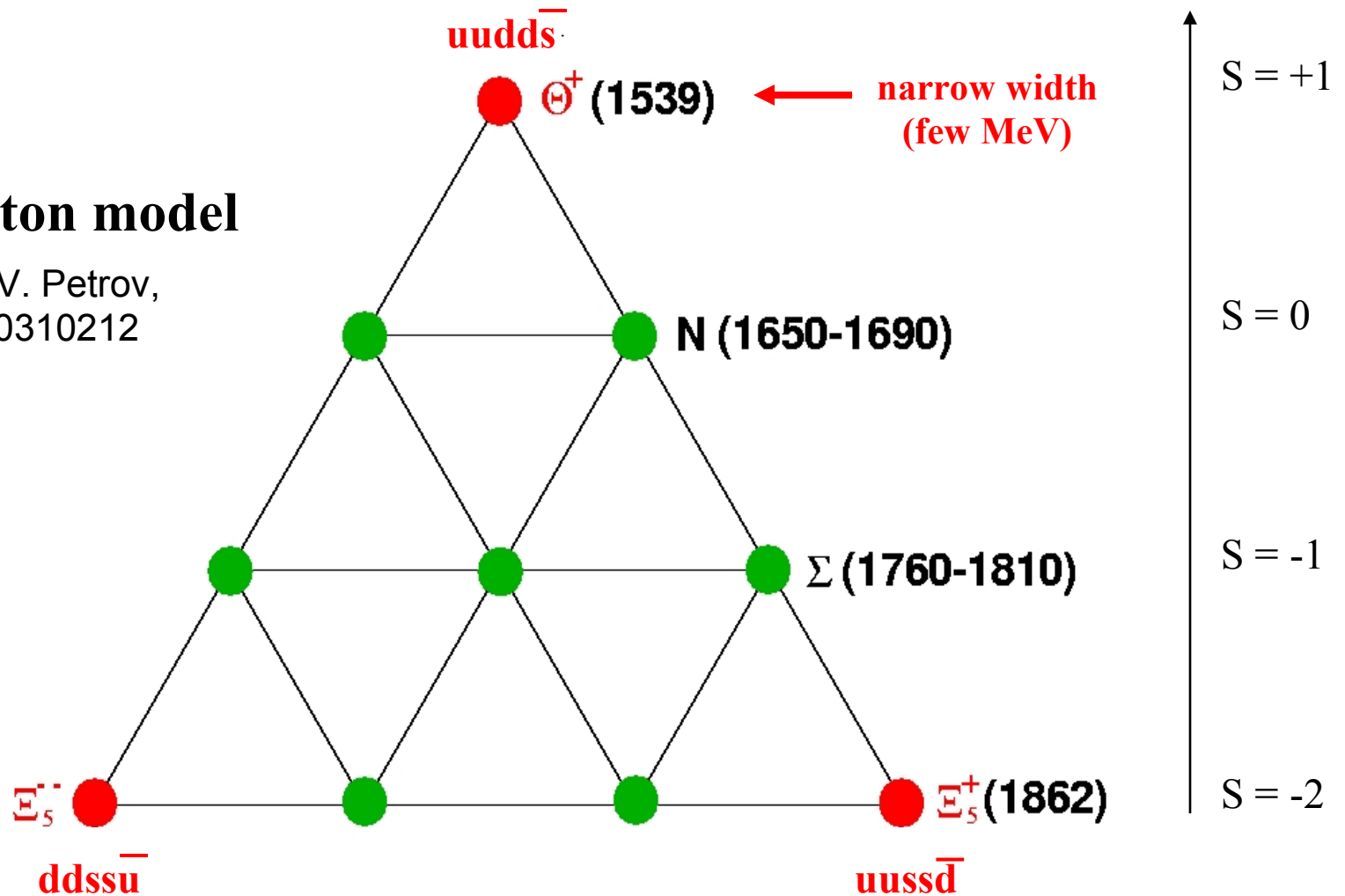
- Baryons whose **minimum quark content is 5**
- Existence **not forbidden** by QCD
- “**Non-exotic**” pentaquarks ($qqqq\bar{q}$)
 - The **antiquark** has the **same flavor** as one of the other quarks
 - Difficult to distinguish from 3-quark baryons
- “**Exotic**” pentaquarks ($qqqq\bar{Q}$)
 - The **antiquark** has a **different flavor** from the other 4 quarks
 - **Quantum numbers** different from any 3-quark baryon
 - Unique identification using experimental conservation laws



The pentaquark anti-decuplet

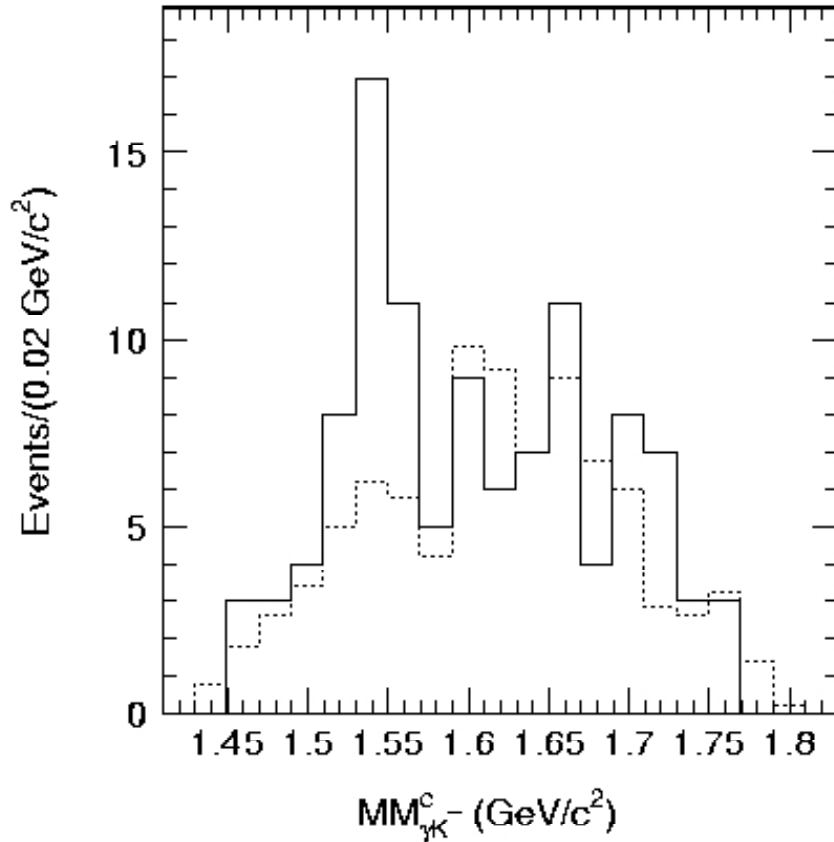
Chiral-soliton model

D. Diakonov, V. Petrov,
arXiv:hep-ph/0310212



First observation: LEP/SPring-8

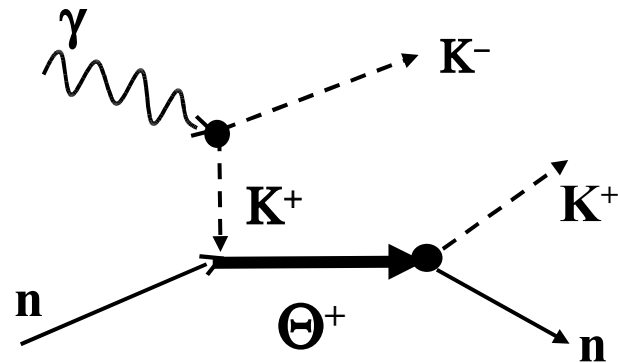
T. Nakano et al., PRL91, 012002 (2003)



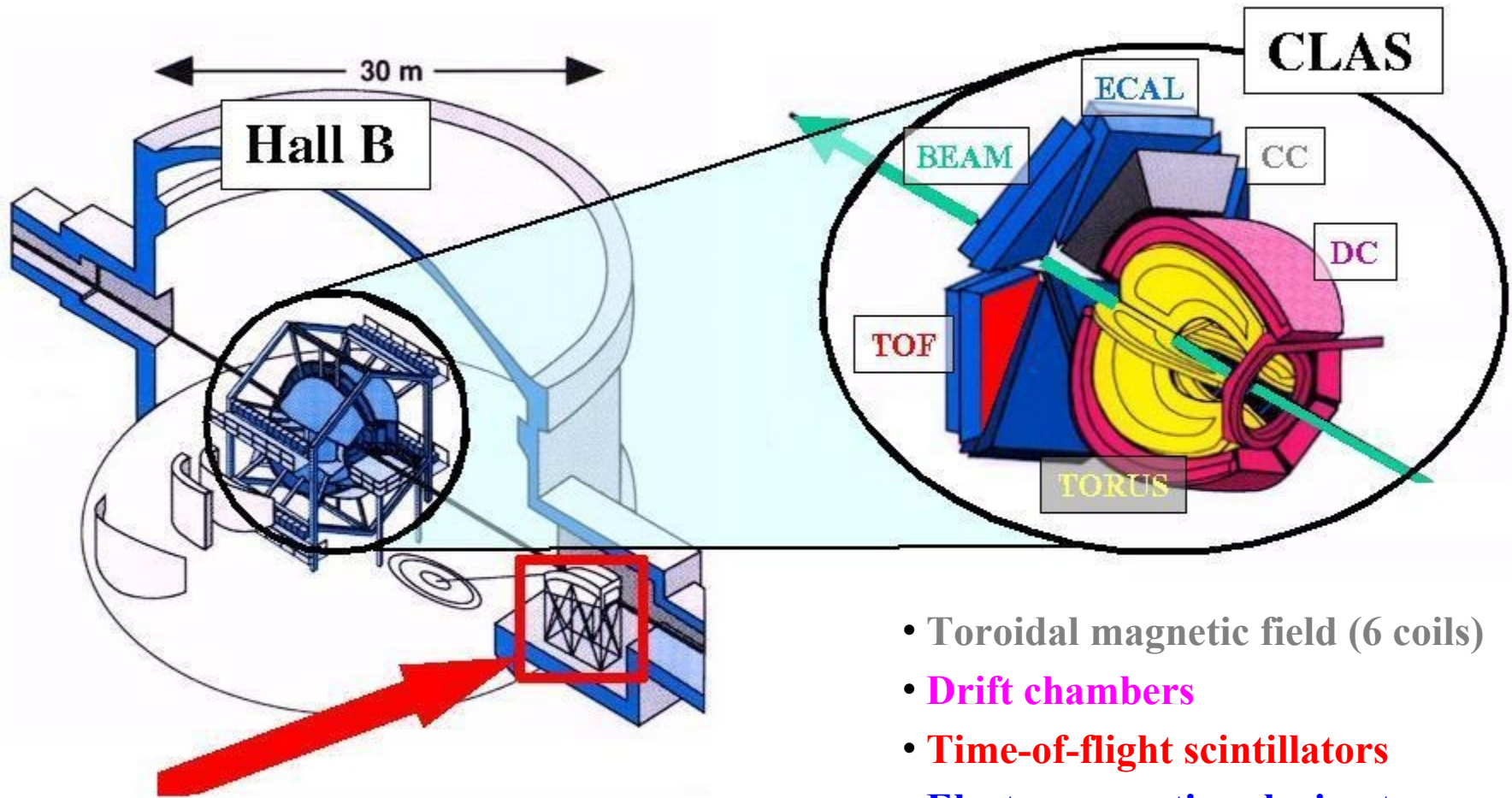
$M = (1.54 \pm 0.01) \text{ GeV}/c^2$
Statistical significance: 4.6σ

$$\gamma C \rightarrow K^+ K^- (n)$$

- n identified by $K^+ K^-$ missing mass
- Θ^+ identified by K^- missing mass
- cut on $\phi \rightarrow K^+ K^-$ (background reaction)
- Fermi motion corrections



The CLAS detector at JLAB

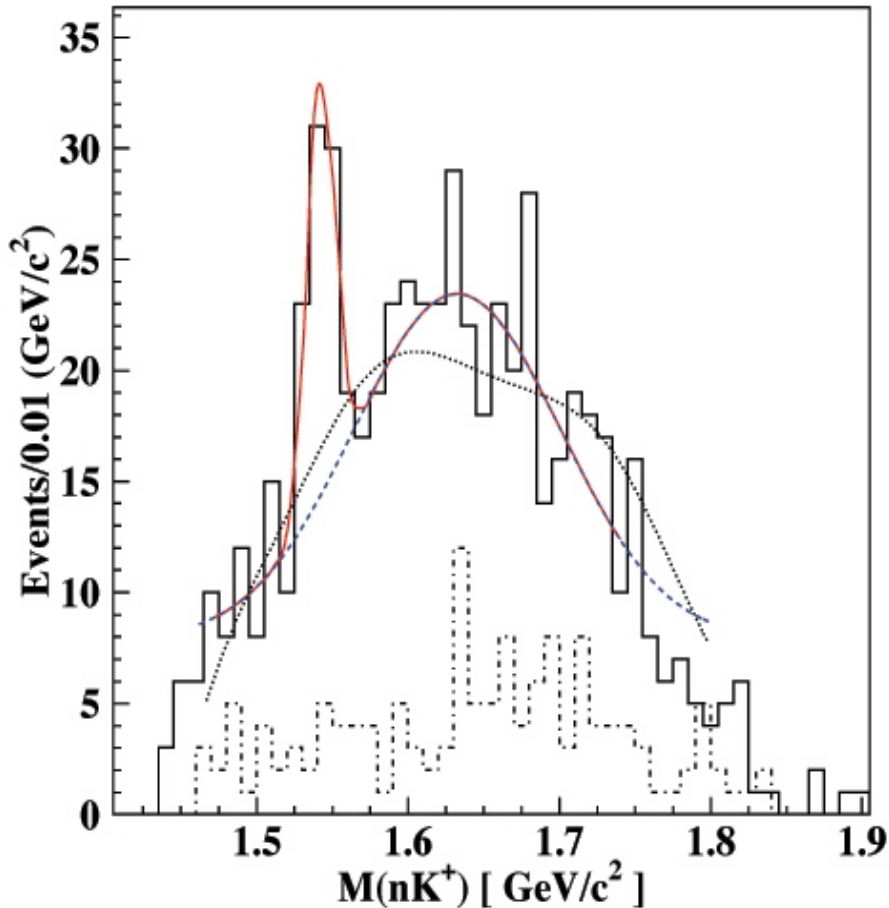


Bremsstrahlung photon tagger

- Toroidal magnetic field (6 coils)
- **Drift chambers**
- **Time-of-flight scintillators**
- **Electromagnetic calorimeters**
- Cherenkov Counters

The confirmation: CLAS-d

S. Stepanyan et al., PRL91, 252001 (2003)



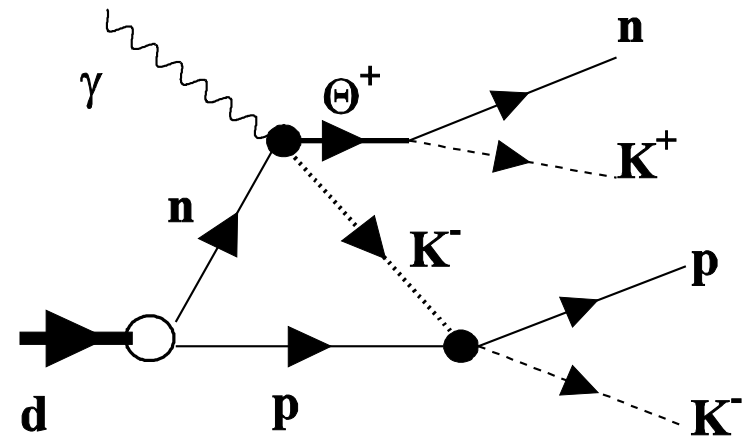
$M = (1.542 \pm 0.005) \text{ GeV}/c^2$

Statistical significance: $(5.2 \pm 0.6) \sigma$

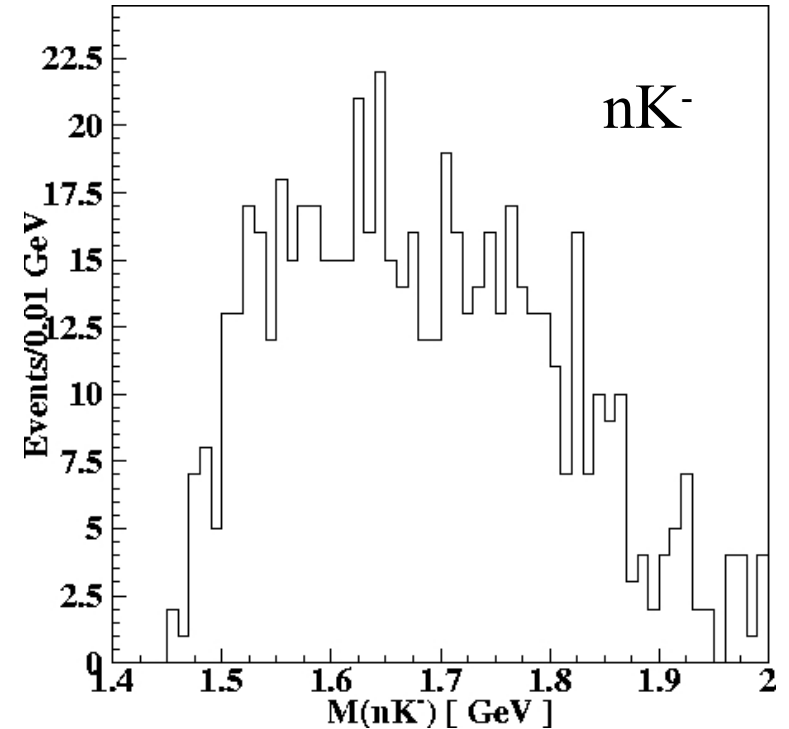
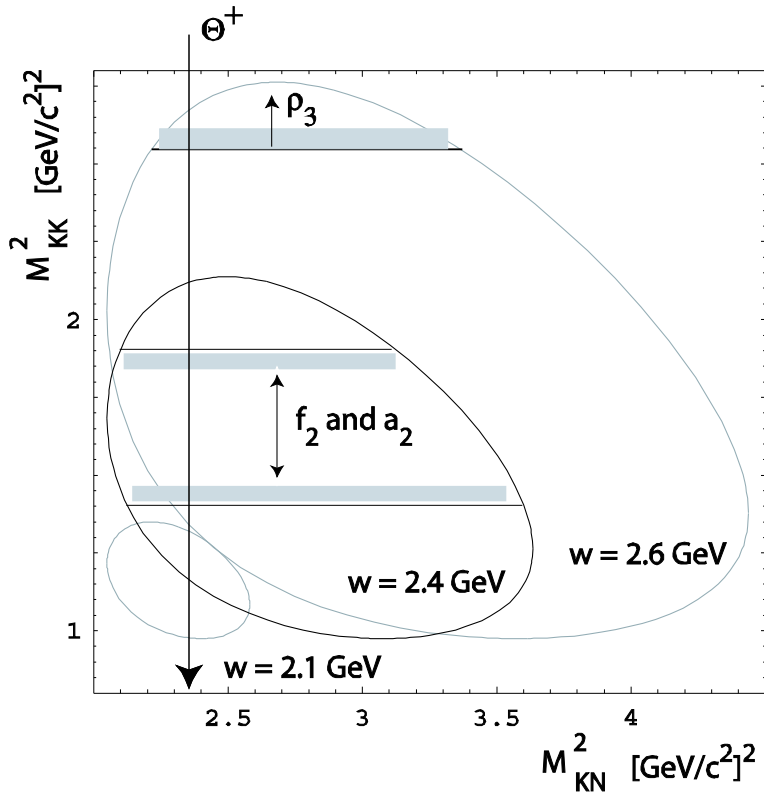


First **exclusive** measurement

- **No Fermi motion corrections**
- Final state identified with **less background**
- **Removal cuts:**
 - ϕ : $M(K^+K^-) < 1070 \text{ GeV}/c^2$
 - Λ^* : $1.485 < M(pK^-) < 1.551 \text{ GeV}/c^2$
 - $p_n < 80 \text{ MeV}/c$ (**no n spectator**)
 - $p_{K^+} < 1 \text{ GeV}/c$ (**bgk on $M(nK^+)$**)



Is Θ^+ a Kinematical Reflection?



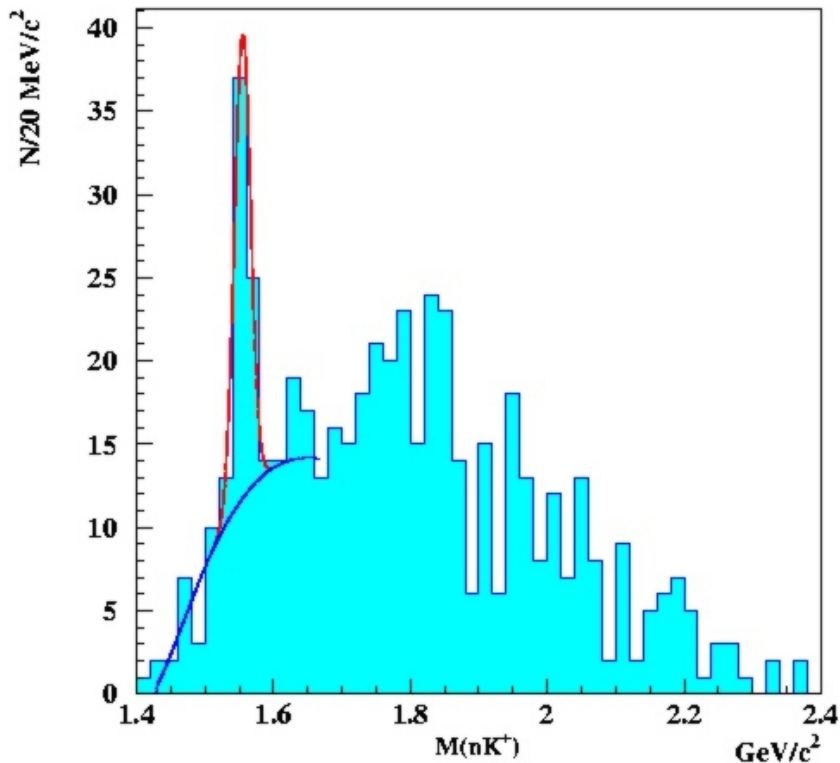
High mass mesons $M \rightarrow K^+K^-$
 can create structures in $M(NK)$
 (A. Dzierba et al., hep-ph/0311125)



But **no structures** seen in
 $M(NK^-)$ at 1.54 GeV/c!

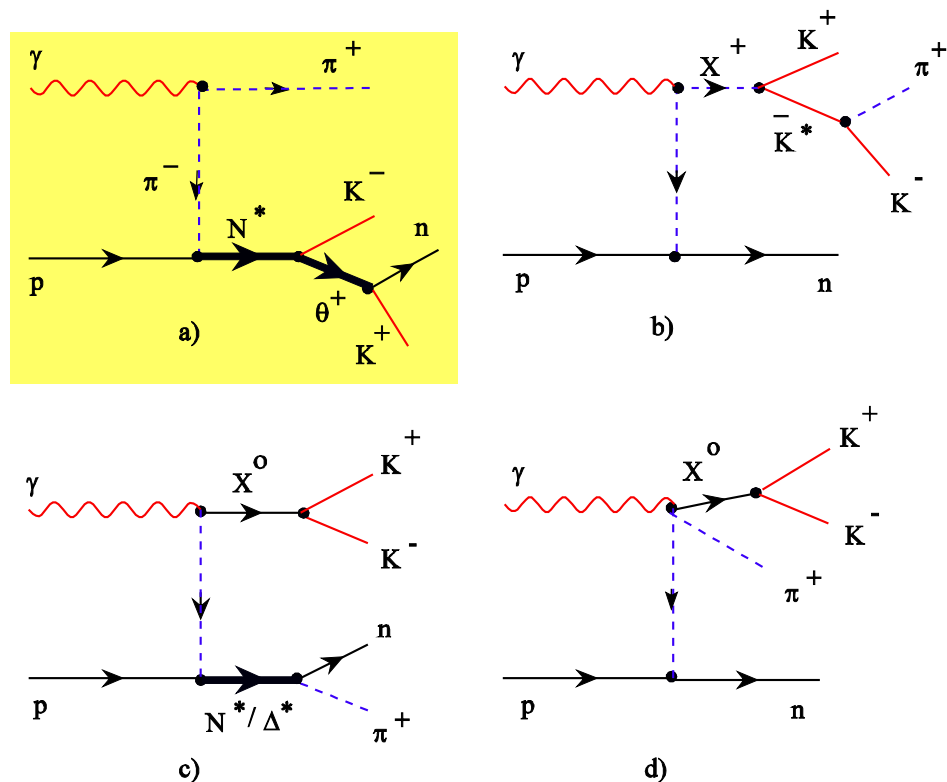
First Observation on the Proton: CLAS-p

V. Kubarovski et al., PRL92, 032001 (2004)



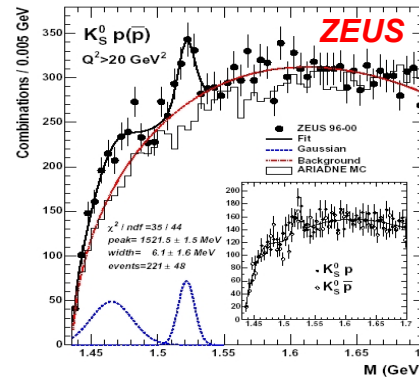
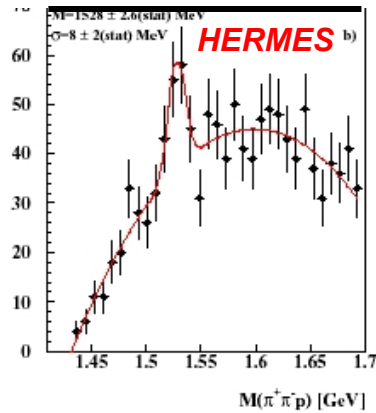
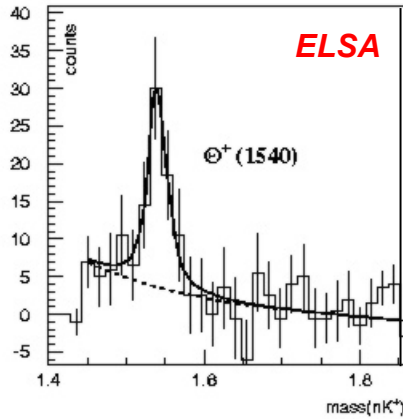
$M = (1.555 \pm 0.010) \text{ GeV}/c^2$
 Statistical significance: $(7.8 \pm 1.0) \sigma$

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

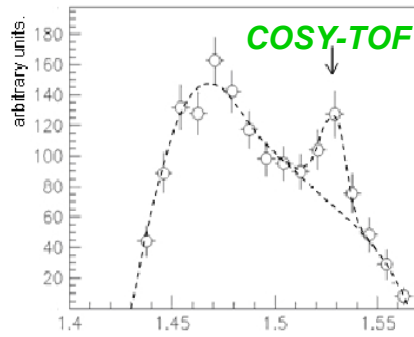
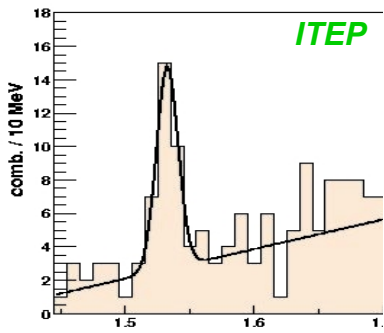


t-channel process a) selected and background processes eliminated with the cuts (c.m.):
 $\cos\theta_{K^+}^* < 0.6$ and $\cos\theta_{\pi^+}^* > 0.8$

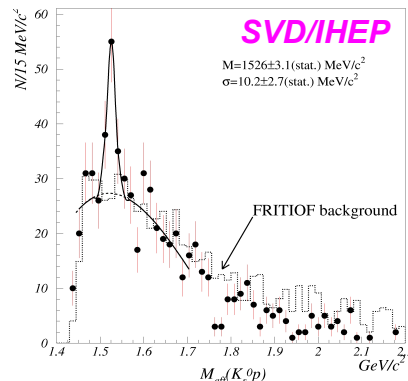
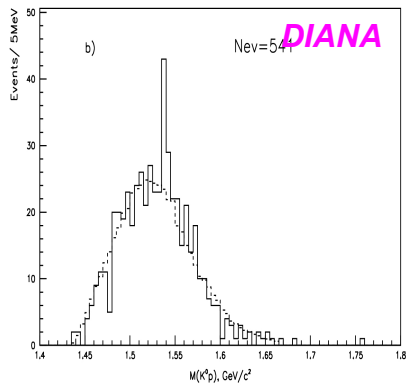
Other Θ^+ Observations



E.m. interactions:
 ELSA: $\gamma p \rightarrow (nK^+)K^0$
 HERMES: $e^+d \rightarrow (pK^0)X$ *
 ZEUS: $ep \rightarrow e(pK^0)X$ *



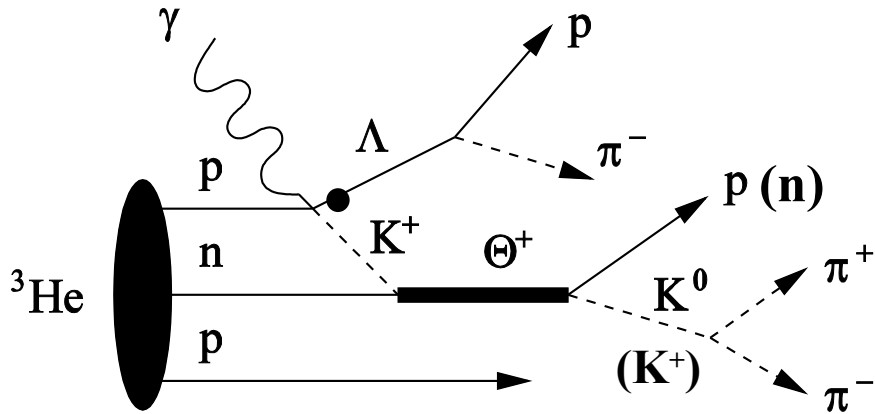
Non-e.m. interactions:
 ITEP: $\nu d, Ne \rightarrow (pK^0)K^0$ *
 COSY-TOF: $pp \rightarrow (pK^0)\Sigma^+$



Hadron-nucleon processes:
 DIANA: $K^+Xe \rightarrow (pK^0)X$ *
 SVD: $pA \rightarrow (pK^0)X$ *

* $S = +1$ not proved

CLAS-analyses in progress: 1) $\gamma^3\text{He} \rightarrow p\Lambda\Theta^+$

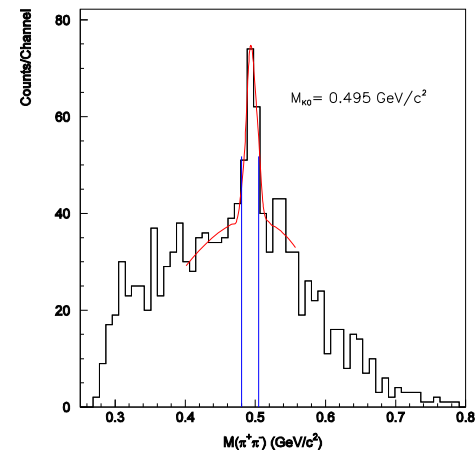
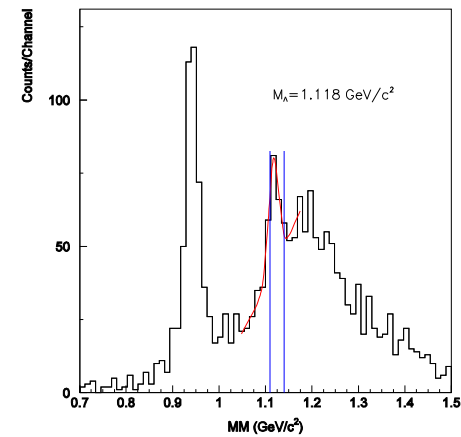


- **No** possibility of **kinematical reflections**
- **S=+1** both for **nK⁺** and **pK⁰**, thanks to Λ
- **No background channels** to remove

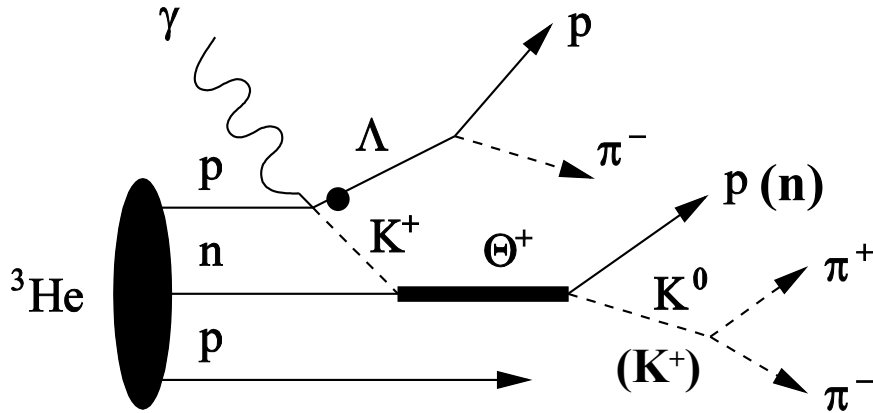
Decay modes: $\Theta^+ \rightarrow K^0 p$ $\Lambda \rightarrow p\pi^-$ $K^0 \rightarrow \pi^+\pi^-$
 $\Theta^+ \rightarrow K^+ n$ $\Lambda \rightarrow p\pi^-$

3 different topologies (exclusive) analyzed:

1) $pp\pi^+\pi^-$ detected, **missing Λ** (case $\Theta^+ \rightarrow pK^0$)

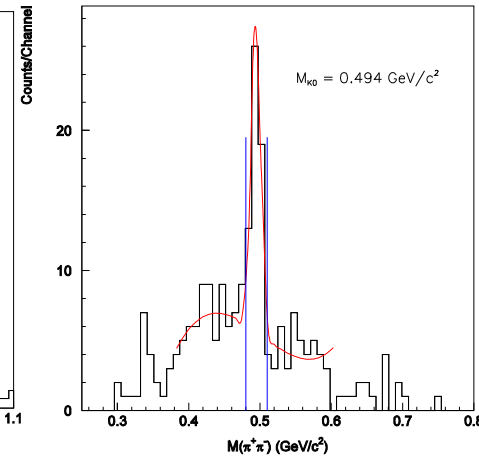
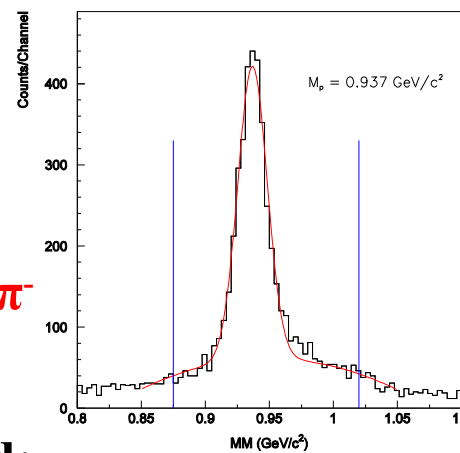


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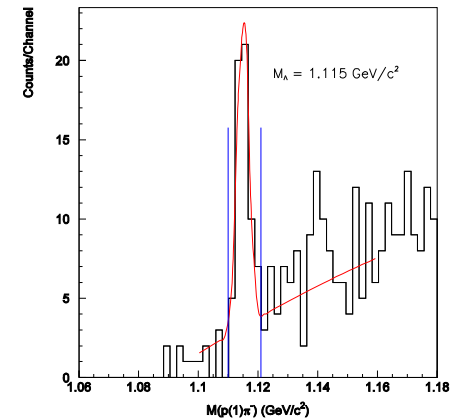
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 $\Theta^+ \rightarrow K^+ n$ $\Lambda \rightarrow p\pi^-$

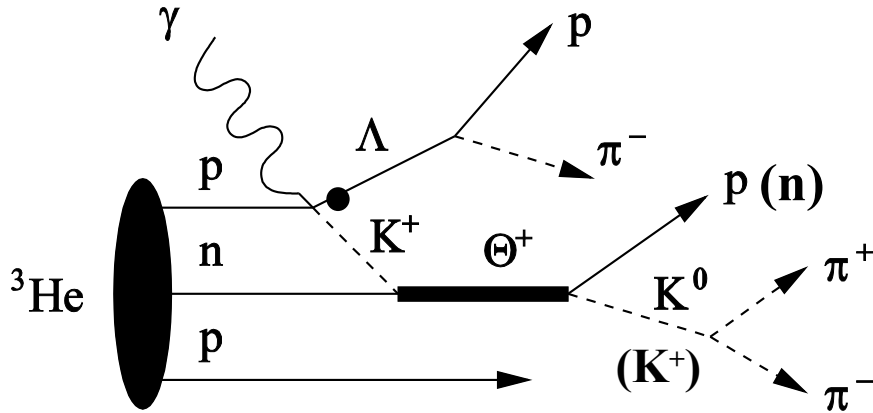


3 different topologies (exclusive) analyzed:

- 1) $pp\pi^+\pi^-$ detected, missing Λ (case $\Theta^+ \rightarrow pK^0$)
- 2) $pp\pi^+\pi^-$ detected, **missing p** (case $\Theta^+ \rightarrow pK^0$)



CLAS-analyses in progress: 1) $\gamma^3\text{He} \rightarrow p\Lambda\Theta^+$

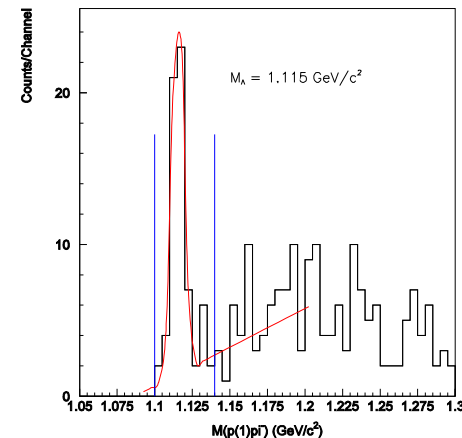
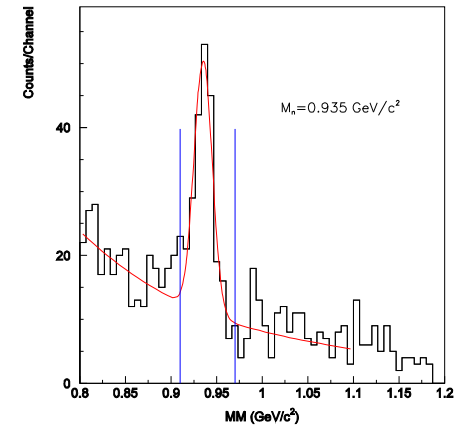


- **No** possibility of **kinematical reflections**
- **S=+1** both for **nK⁺** and **pK⁰**, thanks to Λ
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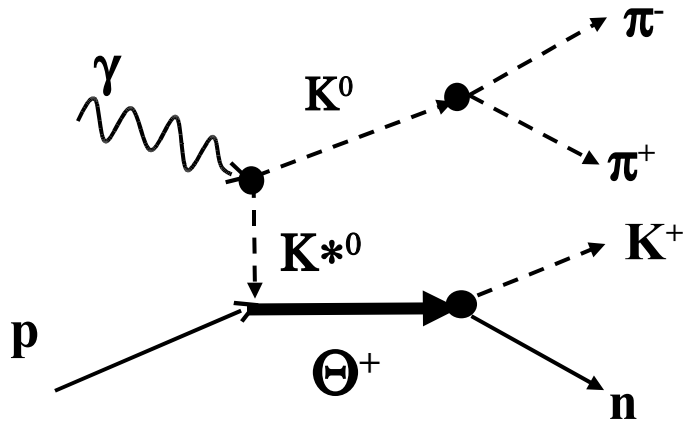
Decay modes: $\Theta^+ \rightarrow K^0 p$ $\Lambda \rightarrow p\pi^-$ $K^0 \rightarrow \pi^+\pi^-$
 $\Theta^+ \rightarrow K^+ n$ $\Lambda \rightarrow p\pi^-$

3 different topologies (exclusive) analyzed:

- 1) $pp\pi^+\pi^-$ detected, missing Λ (case $\Theta^+ \rightarrow pK^0$)
- 2) $pp\pi^+\pi^-$ detected, missing p (case $\Theta^+ \rightarrow pK^0$)
- 3) $ppK^+\pi^-$ detected, **missing n** (case $\Theta^+ \rightarrow nK^+$)

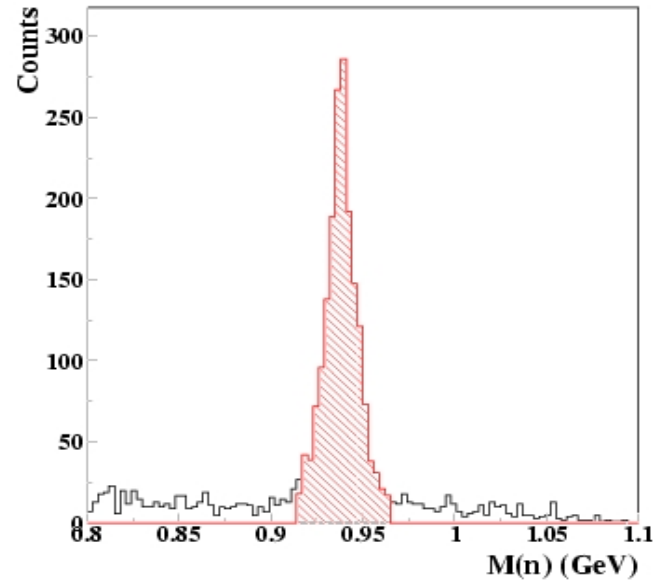
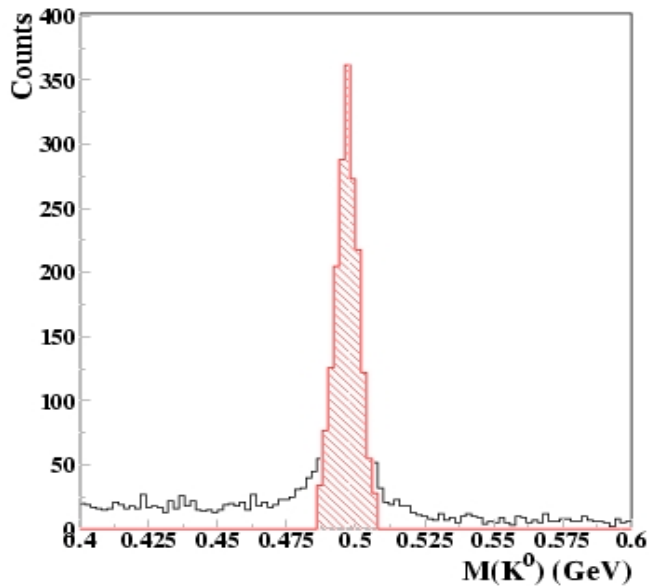


CLAS-analyses in progress: 2) $\gamma p \rightarrow \Theta^+ \bar{K}^0$

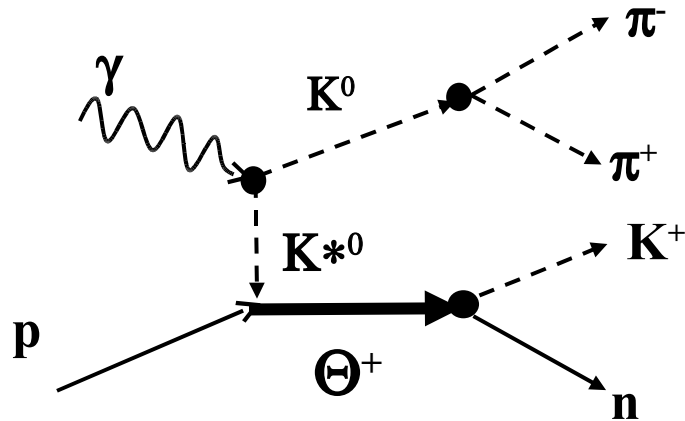


Decay modes: $\Theta^+ \rightarrow K^+ n$ $K^0 \rightarrow \pi^+ \pi^-$

- three charged particles detected
- missing mass technique for n



CLAS-analyses in progress: 2) $\gamma p \rightarrow \Theta^+ \bar{K}^0$



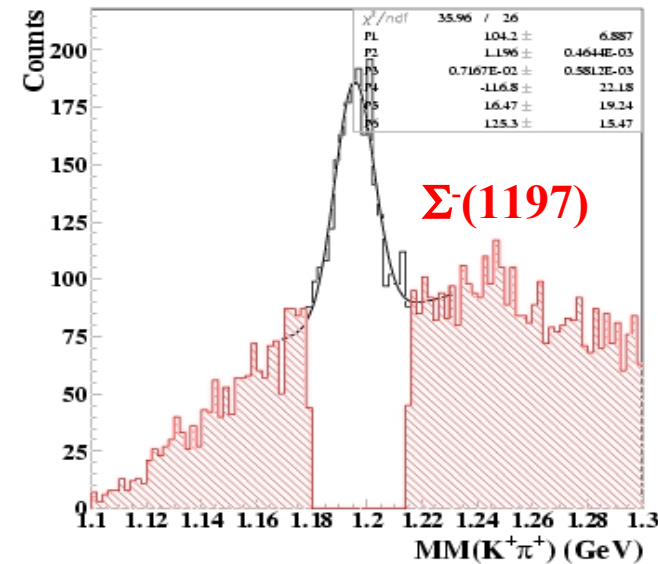
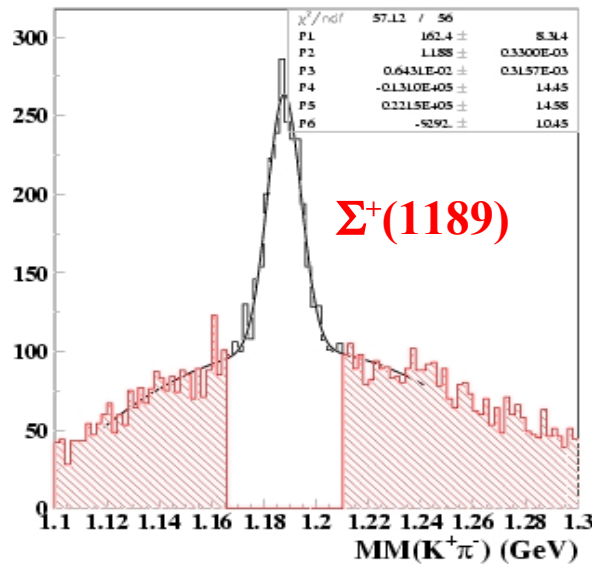
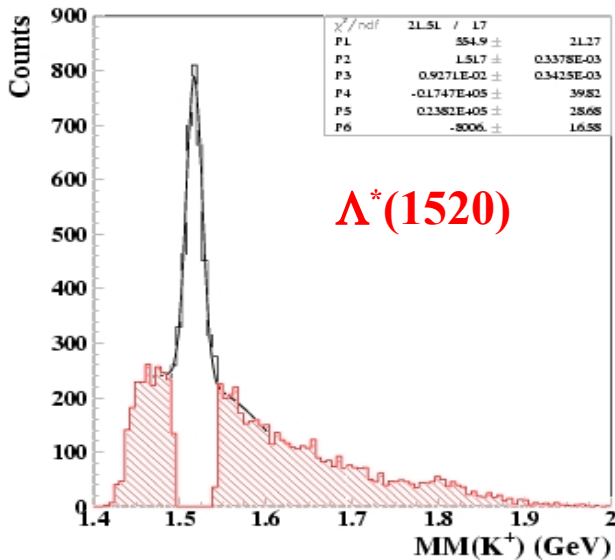
Decay modes: $\Theta^+ \rightarrow K^+ n$ $K^0 \rightarrow \pi^+ \pi^-$

- three charged particles detected
- missing mass technique for n
- eliminated **background of hyperons** decaying in the same final state

$p \rightarrow \Lambda^*(1520) K^+$

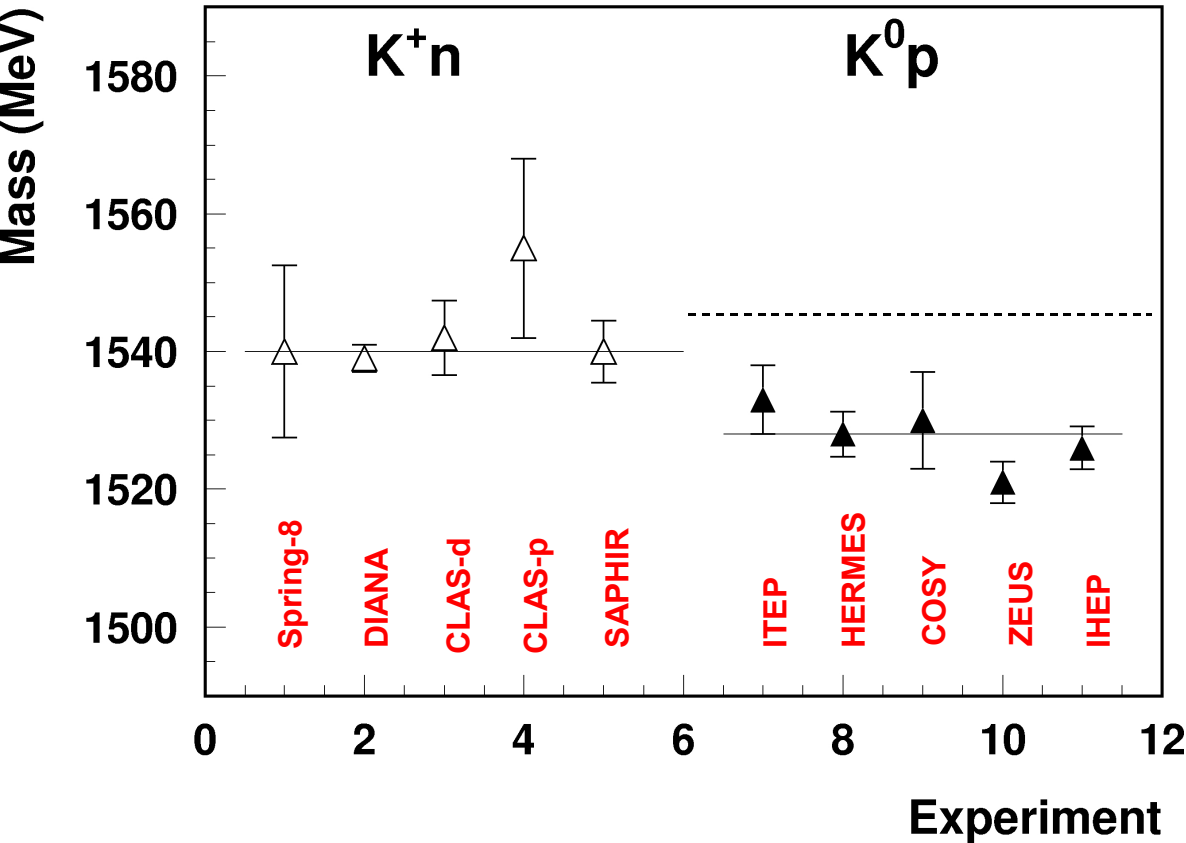
$\Lambda^*(1520) \rightarrow n K^0$

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



Summary on Θ^+

$\Theta^+(1540)$ Mass



- **~ 10 MeV gap** between measured masses
- statistical significance between **4 and 7.8 σ**
- several **non-observations** recently reported (unpublished):

LEP(DELPHI): $e^+e^- \rightarrow nK^+, pK^0$
HERA B: $p+A \rightarrow pK^0$
CDF: $pp \rightarrow pK^0$
HyperCP: pK^0
E690: $pp \rightarrow pK^0$
HERA-B: $p+A \rightarrow pK^0$
ALEPH: pK^0
Phoenix: $d+Au \rightarrow nK^+, pK^0$
BaBar: $e^+e^- \rightarrow nK^+, pK^0$
NA49: $Pb+Pb \rightarrow pK^0$

NEEDED HIGH-STATISTICS EXCLUSIVE MEASUREMENTS!!!!

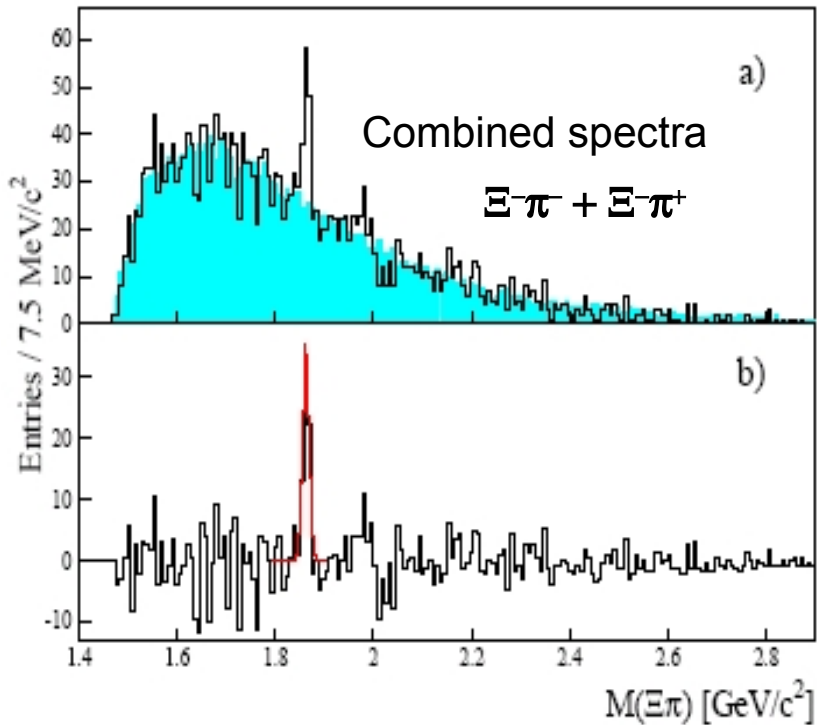


All **high-energy** and **inclusive** but **clearly see known resonances!**

Decuplet partners of Θ^+ : search for Ξ_5^- , Ξ^0

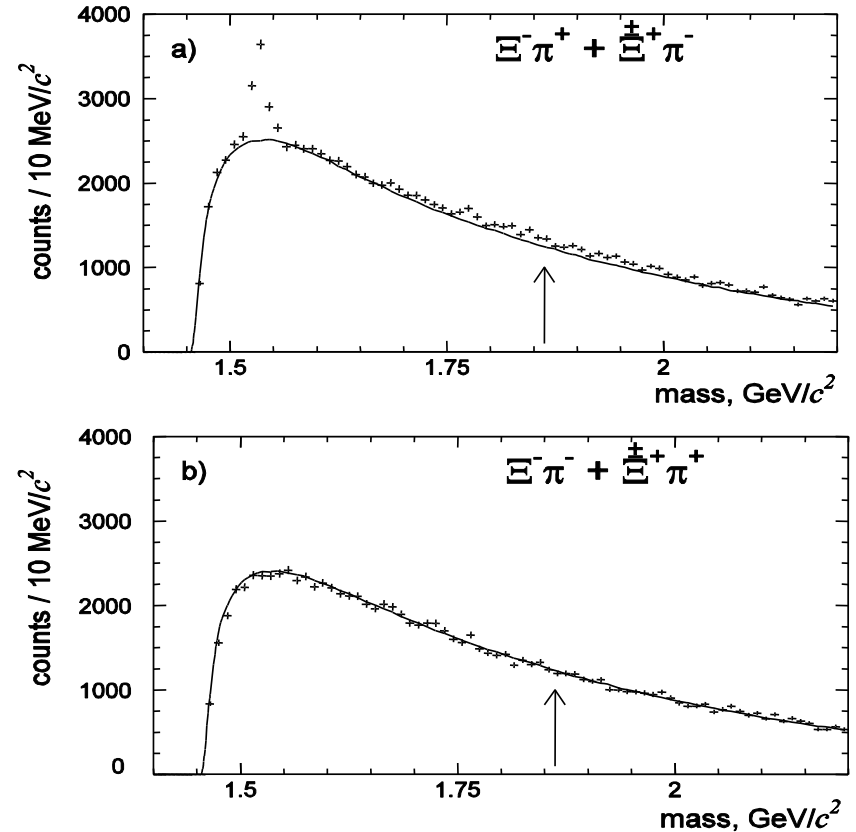
NA49 pp $E_{\text{cm}} = 17.2$ GeV

$M = 1.862 \pm 0.002$ GeV



C. Alt, et al., Phys.Rev.Lett.92, 042003 (2004)

HERA-B p+A 940 GeV/c



hep-ex/0403020

Pentaquark today: open issues

- confirmation of **existence** of Θ^+ with **high statistics**
- precise determination of the **mass** of Θ^+
- spin, isospin, parity
- production mechanisms
- possible **excited states** of Θ^+
- coupling **N^* to Θ^+**
- confirmation existence of **other exotic** members of decuplet



The experimental program currently underway at CLAS intends to address these issues

CLAS G10: search for Θ^+ on deuterium

Reactions to study:

$$\gamma d \rightarrow p K^- K^+ n \quad \Theta^+ \rightarrow n K^+$$

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

$$\gamma d \rightarrow p K^- K^0 \quad \Theta^+ \rightarrow p K^0 \quad K^0 \rightarrow \pi^+ \pi^-$$

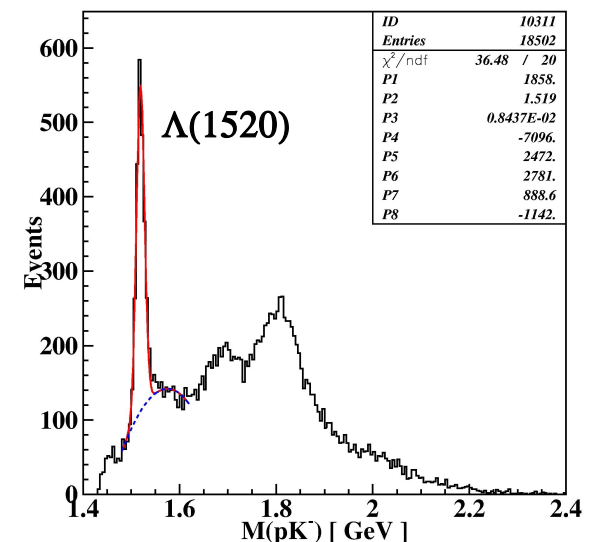
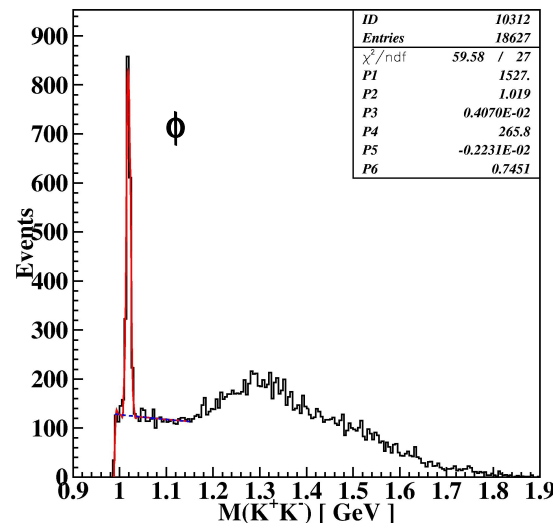
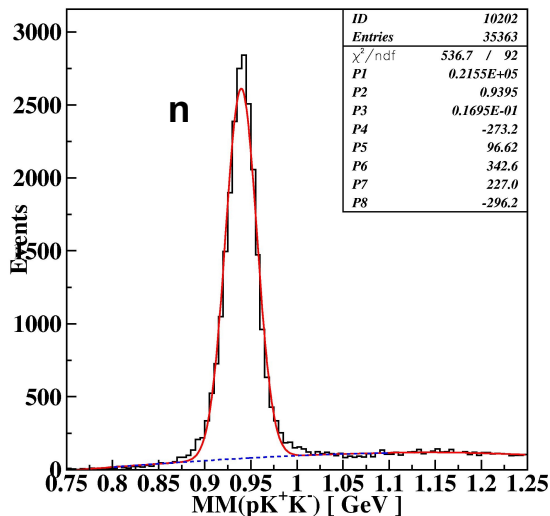
$$\gamma n' \rightarrow K^- K^+ n \quad \Theta^+ \rightarrow n K^+$$

- data taking finished end of May

- $E_\gamma = 0.8 - 3.59$ GeV

Fermi momentum corrections
(to compare with SPring-8)

G10 “online” plots: case $\gamma d \rightarrow p K^- K^+(n)$



CLAS G11: search for Θ^+ on proton

Reactions to study:

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

$$\gamma p \rightarrow K^0 K^0 p \quad \Theta^+ \rightarrow p K^0 \quad K^0 \rightarrow \pi^+ \pi^-$$

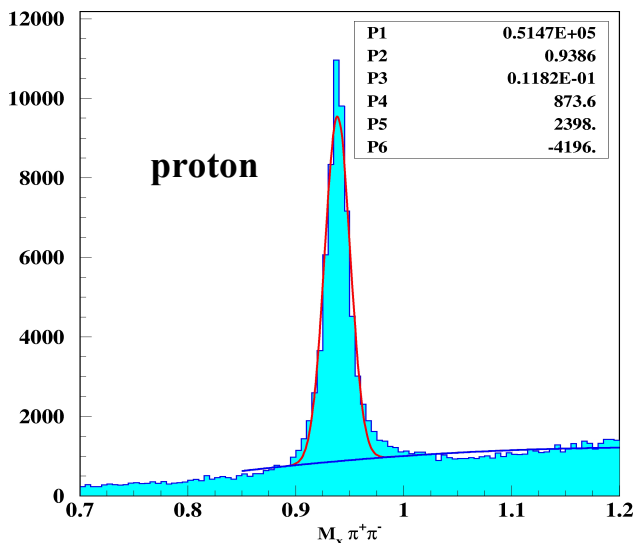
$$\gamma p \rightarrow K^- K^+ \pi^+(n) \quad \Theta^+ \rightarrow n K^+$$

$$\gamma p \rightarrow p K^- K^+ \quad \Theta^{++} \rightarrow p K^+$$

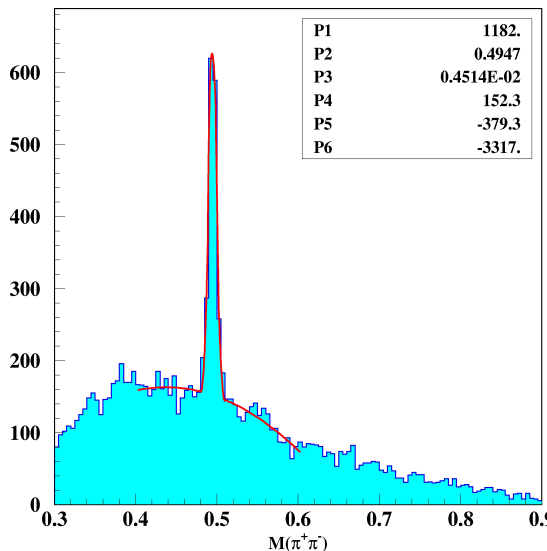
- running now
- $E_\gamma = 0.8 - 3.59$ GeV
- new start counter

G11 “online” plots

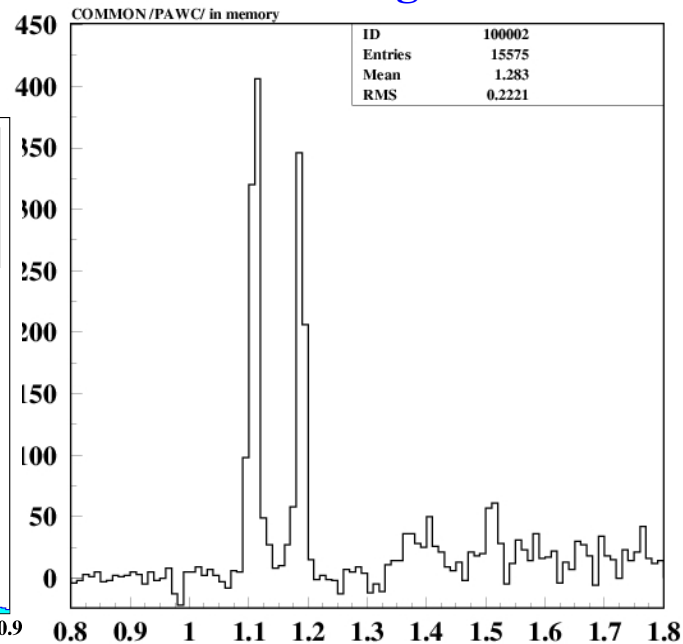
$$\gamma p \rightarrow \pi^+ \pi^- (p)$$



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



K⁺ MissingMass



Summary and outlook

- possible **existence of pentaquarks** gave new boost to hadron spectroscopy and theoretical calculations
- **10 Θ^+ signals** reported so far, **but**:
 - **low statistics**
 - **discrepancies** in measured **masses**
- several reports of **non-observations**
- need of **high-statistics** dedicated experiments to:
 - establish **existence** of Θ^+
 - study its **properties**
 - find **other pentaquarks**
- **experiments underway and planned at CLAS** may solve this dilemma

STAY TUNED...