Pentaquarks: facts, mystery, prospects …

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Nuclear Physics Seminar

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Outline:

- Some History
- The modern era
- Experimental data, how to claim a discovery?
- Has Pentaquark been observed?
- Is it's existence disproved?
- What must be done next?

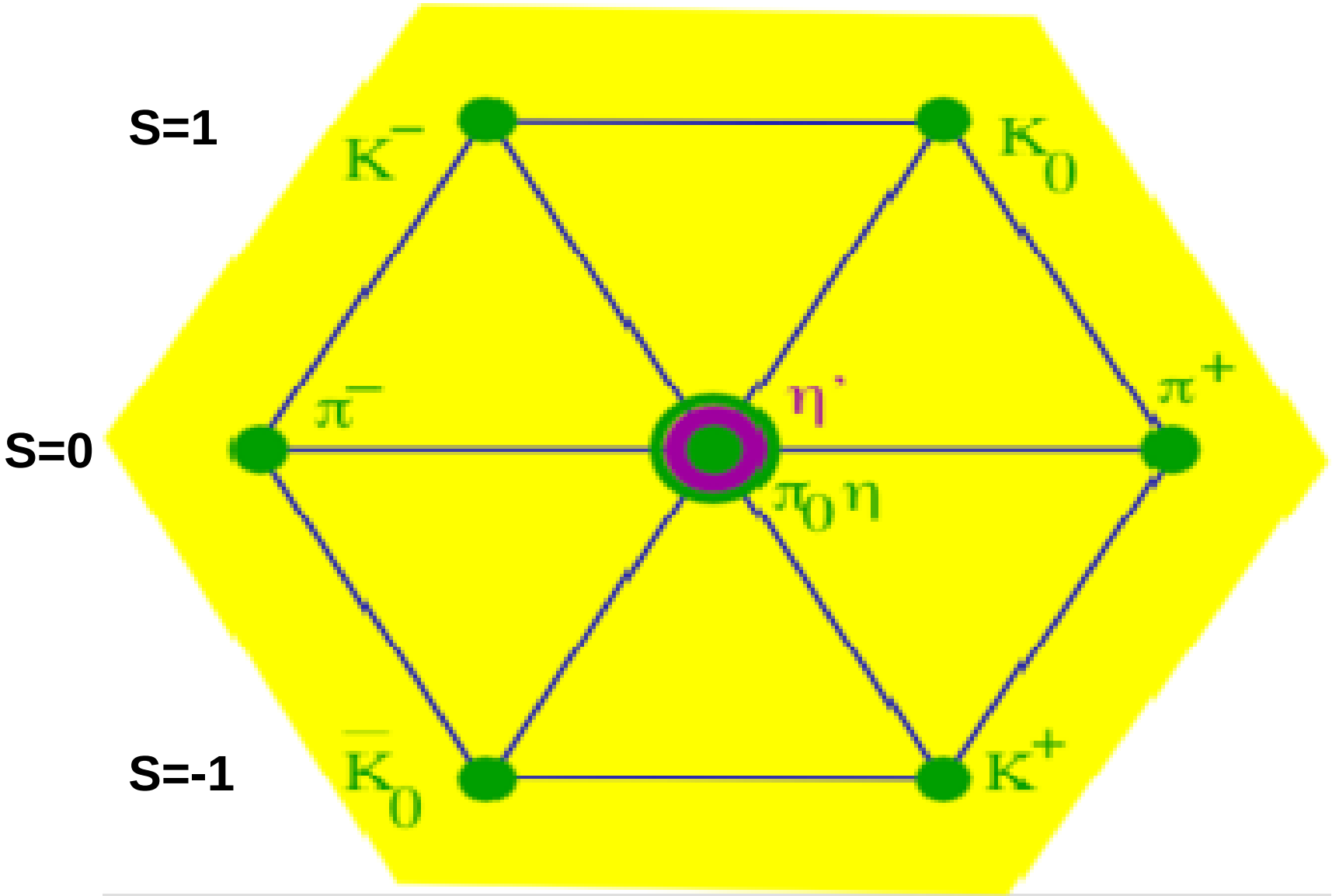
KN Scatteing and Z*-resonance

- **The search of the KN resonances started even before the advent of the constituent quark model**
- **In late 70's and 80's it was realized that the resonance in K+n system will be manifestly exotic with 5-q content**

  However the search was conducted mostly in the region above 1700 MeV

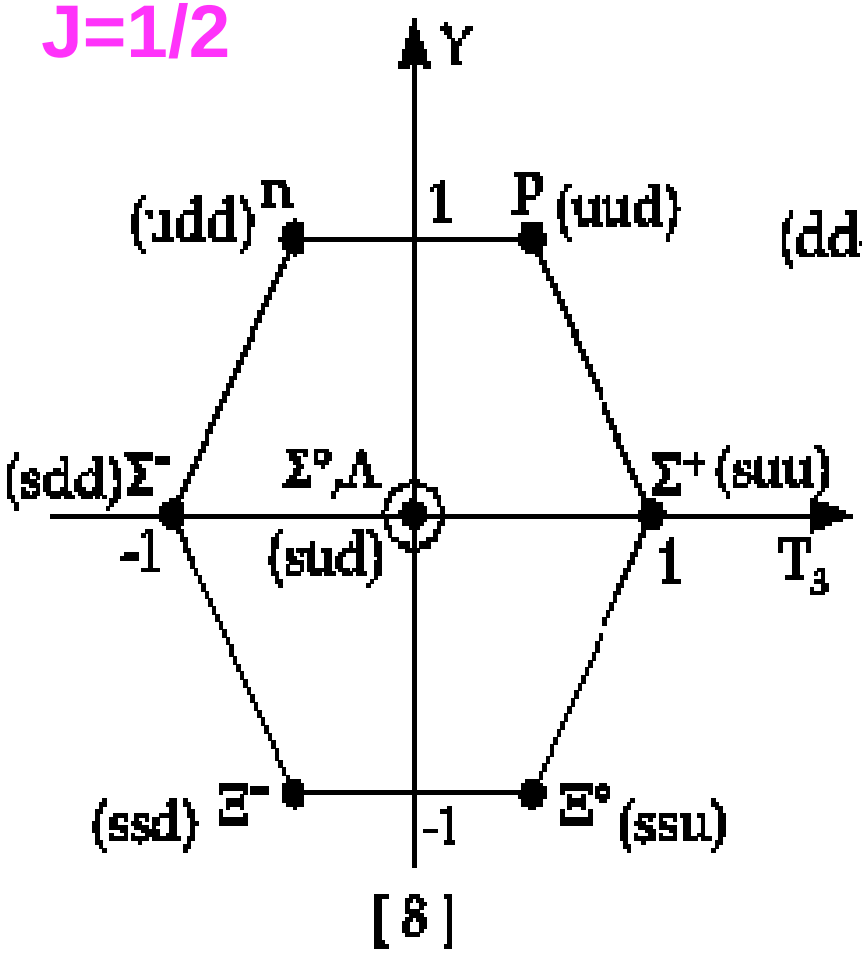
  No conclusive results have been obtained

Constituent Quark Model: Mesons

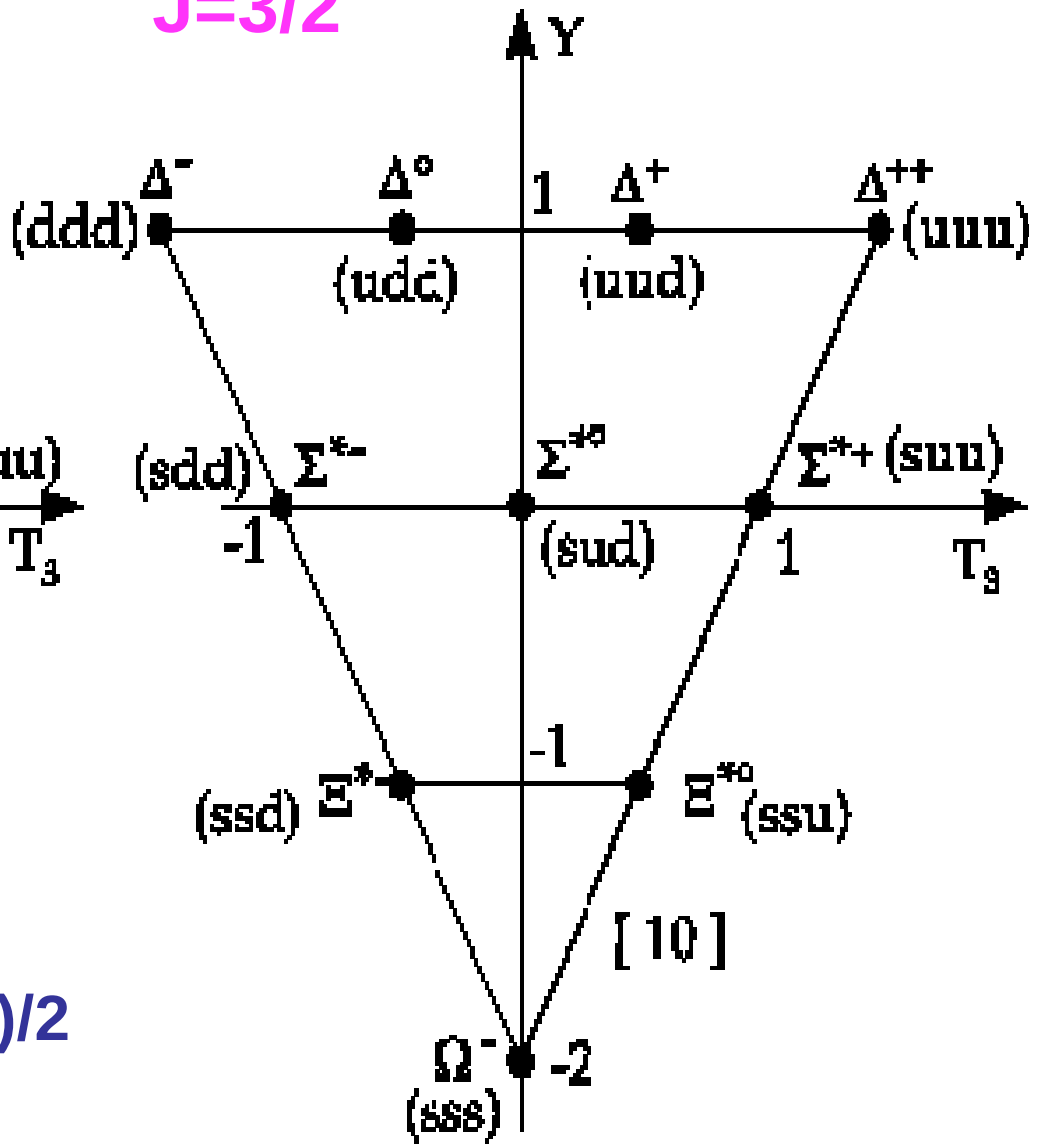


Constituent Quark Model: Baryons

J=1/2



J=3/2

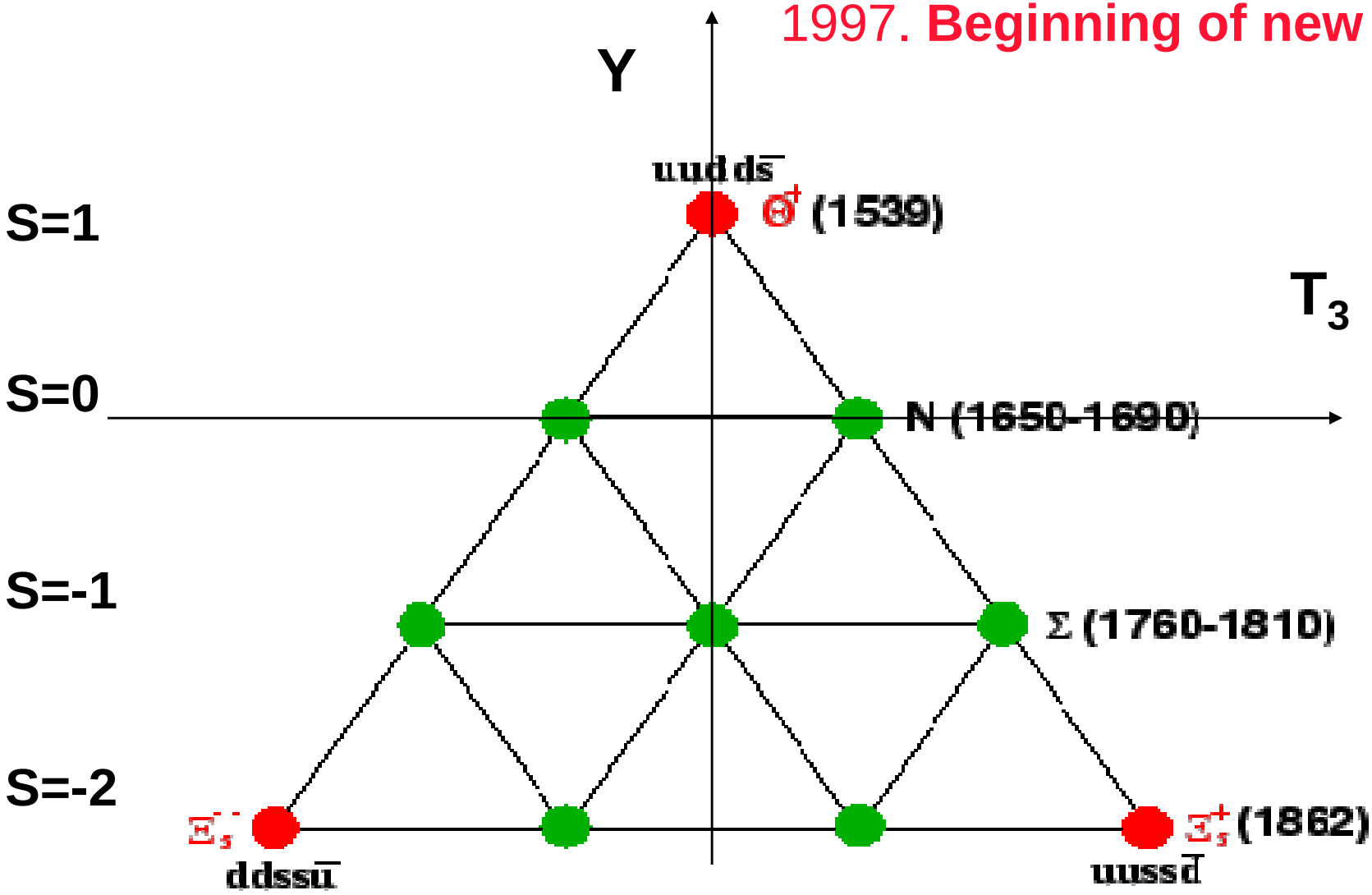


Hypercharge: Y =(B+S)/2

Charge: Q = T_3 + Y

Pentaquarks: $\overline{10}$ of SU(3) symmetry

Diakonov,Petrov,Polyakov
1997. **Beginning of new era.**



How to produce Θ^+ ?

Θ^+ decays to K^+n or K^0p

Therefore two main possibilities:

- **S-channel formation:** $K^+n = K^0p$
- **or production mechanism:**

$\gamma + p = K^0 K^+n$; $\gamma + p = \overline{K^0} K^0p$

$\gamma + n = K^- K^+n$; $\gamma + n = K^- K^0p$

more proceses:

$p+p = \Theta^+ X$; $e+e- = \Theta^+ \Theta^- X$

$e+p = \Theta^+ X$ **and so on …**

Where Θ^+ was searched for?

Since 2003 almost all particle and nuclear physics collaborations have been involved, About few thousand physicists !
~1000 (or more) papers are published!

Japan:
SPRING-8
BELLE

USA: CLAS, BABAR,D0, HyperCP, STAR, PHENIX

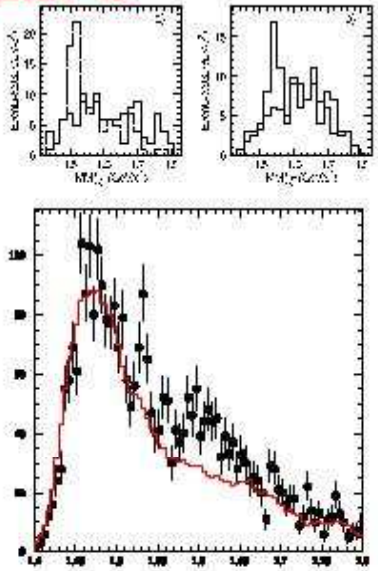
Europe:
SAPHIR, COSY, HERMES, ZEUS, H1,HERA-B, NOMAD,ALEPH

Russia:
DIANA, SVD, Dubna, SPHINX

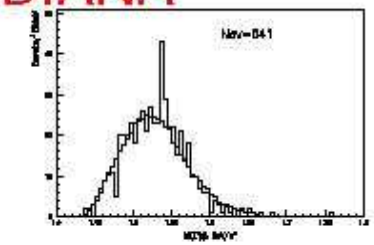
China:
BES

Experimental Status: Since 2003…

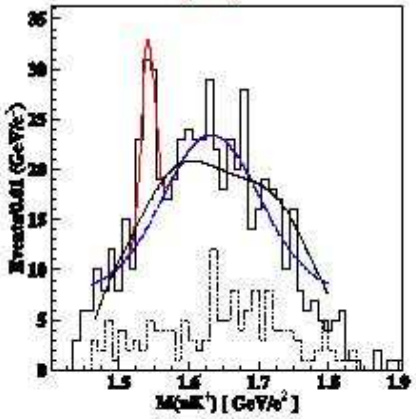
LEPS



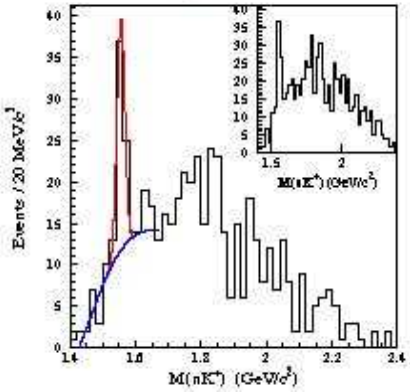
DIANA



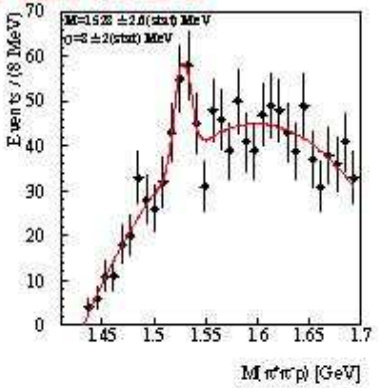
CLAS (*d*)



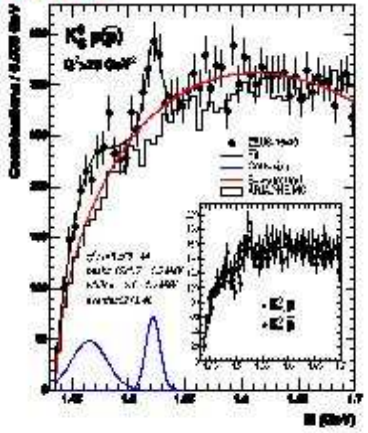
CLAS (*p*)



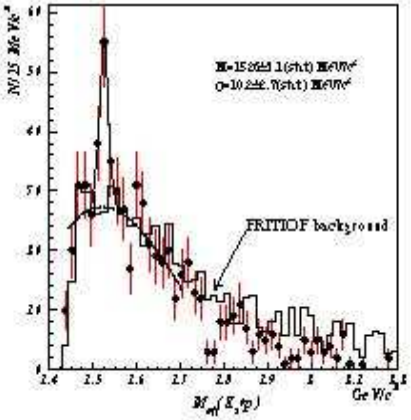
HERMES

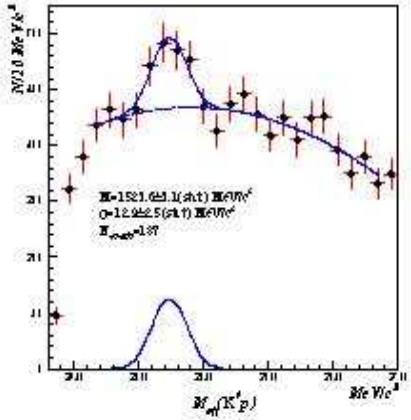


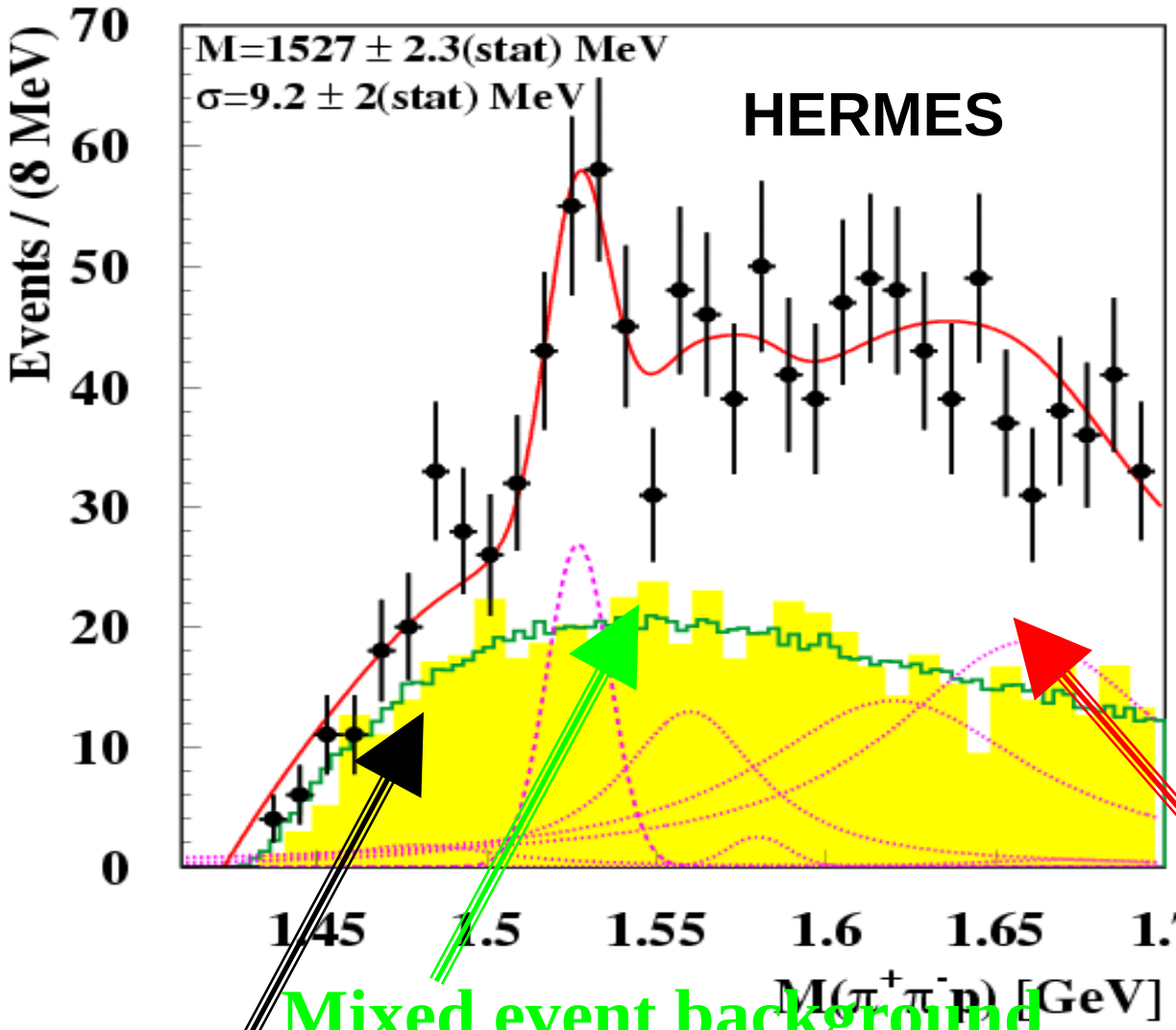
Zeus



SVD-2







"entia non sunt multiplicanda praeter necessitatem"
Lex Parsimoniae or Occam's razor
14th Century

New resonance is needed at ~1530 MeV

Mixed event background

PYTHIA

excited Σ* hyperons
(not included in Pythia6)

Tampa 2005

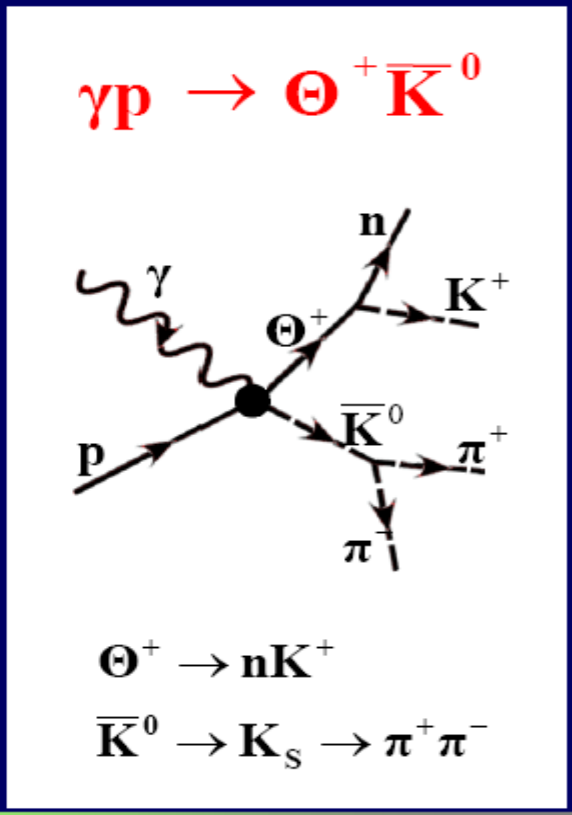
g11@JLab: Spectroscopy of Exotic Baryons with CLAS
Search for Ground and Excited States

Proposed measurement and Primary Goals:

- search for $\Theta^+(1540)$ and possible excited states in γ–p interaction above threshold (E_γ = 1.6 – 3.8 GeV)
- collect more than 10 times the statistics of previous measurements in the same kinematics
- establish the mass of any observed peak with 2 MeV accuracy
- determine total and differential cross section

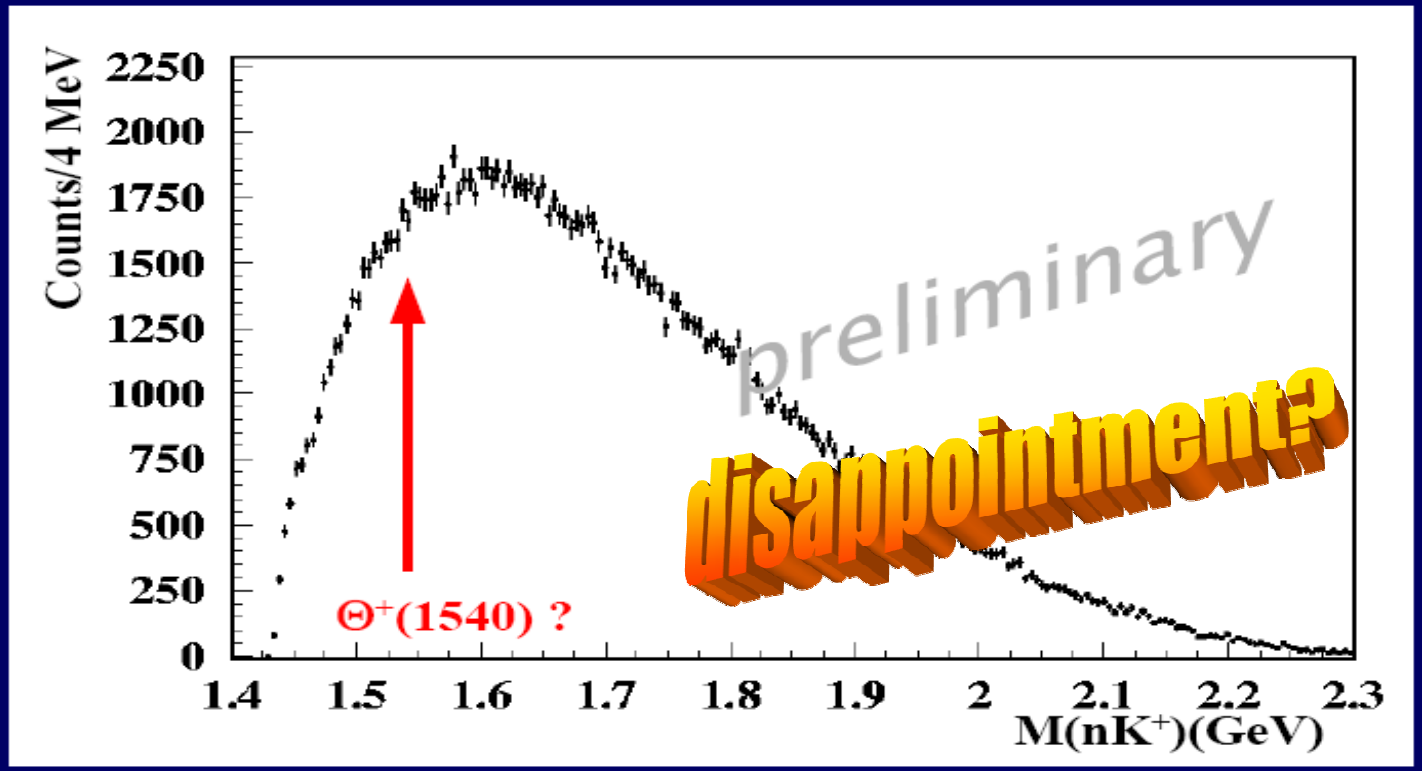
Status of the experiment

- New experiment approved by JLab PAC25 in January 2004.
- Run in May–July 2004, with a total of $7 \cdot 10^9$ triggers recorded (Luminosity ~70 pb^{-1})
- Data calibration and processing completed in January 2005
- Preliminary results for this reaction



CLAS at Tampa 2005

nK^+ Mass Spectrum



- the nK^+ mass spectrum is smooth
- no structure is observed at a mass of ~1540 MeV

Where we Stand?

- CLAS set up an upper limit for the photoproduction cross section of a few nb
- Many experiments do not see a signal, but should they see it?
- Some previous positive results still hold
- Is the case closed?
- Can we increase sensitivity to the tiny cross section ?
- What must be done in order to convince ourselves in existence or in absence of the resonance ?
- How to claim a discovery ?

Why pentaquarks are important?

Let me remind you how opportunistic, or I might say schizoid, our conventional, pragmatic approach to hadrondynamics is.

Frank Wilczek: Plenary talk at EPS meeting, Aachen 2003

Speaking about practical spectroscopy with simple models and non-interacting quarks he continues:

This sort of naıve quark model is easy to use and it organizes a lot of data pretty successfully, which is why it's useful and popular. But it's a dead end.

Consideration of pentaquarks brings some serious shortcomings of the naıve quark model into sharp focus.

Experimental challenges or where we stand?

After the CLAS new measurements we know that photoproduction cross section is small

$\sigma(\mathrm{nb})$

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

$\mathrm{E}_\gamma, \mathrm{GeV}$

Ya.Azimov, V.Kuznetsov, M.Polyakovand I.Strakovsky

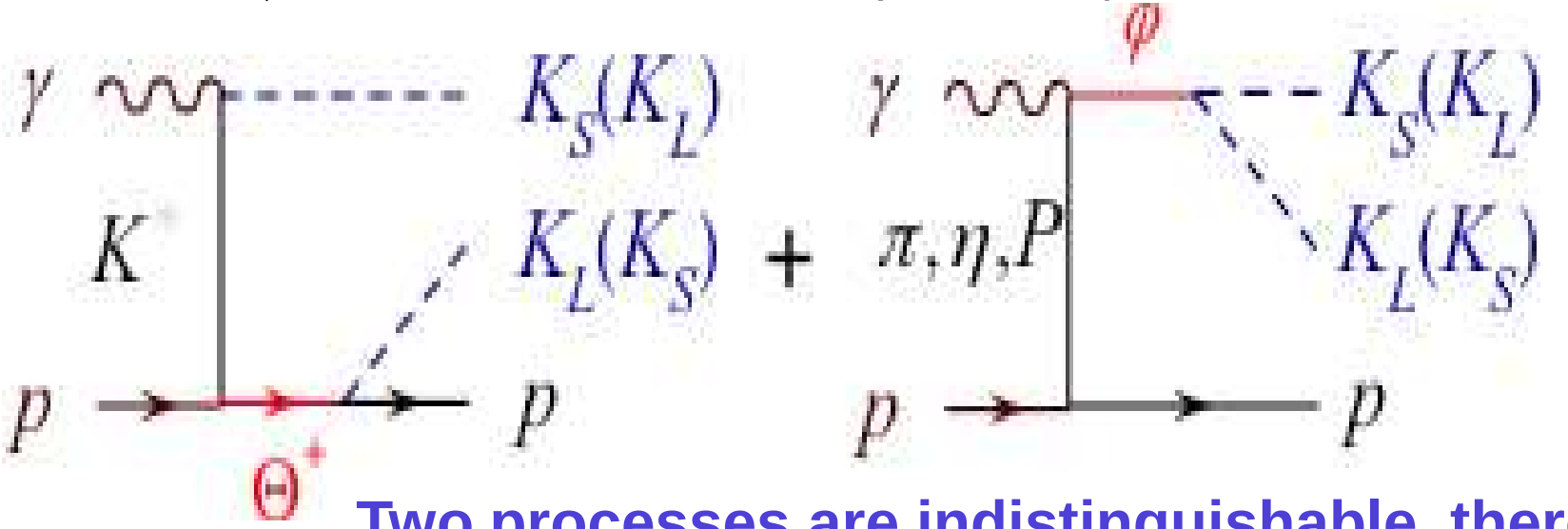
PRD75:054014,2007

Where we stand?

- There are no low energy kaon beams available
- There might be low energy pion beams available at FNAL (or JPARC in the future)
- Is there any way to increase sensitivity of experiments?
- One possibility is to use Quantum Mechanical Interference
- Question is how?

QM Interference between φ and Θ

$$\gamma + p \to p + \phi(K_S K_L)$$
$$\gamma + p \to \Theta^+(pK^0) + \bar{K}^0$$



Two processes are indistinguishable, therefore

$$A^2 = (A_\phi + A_\Theta)^2 = A_\phi^2 + A_\Theta^2 + A_\phi^* A_\Theta + A_\phi A_\Theta^*$$

This might lead to more than order of magnitude enhancement of the Θ^+ !

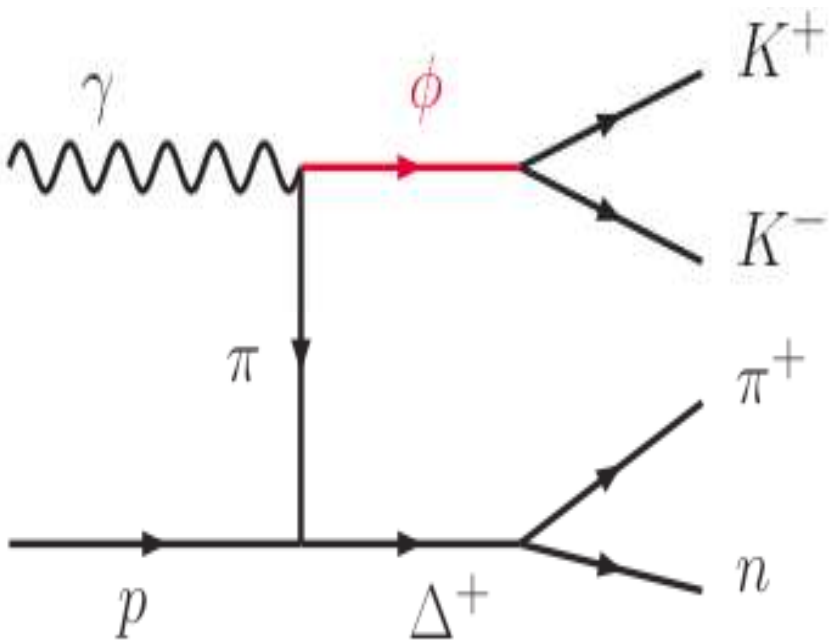
M.Amarian, D.Diakonov and M.Polyakov, hep-ph/0612150

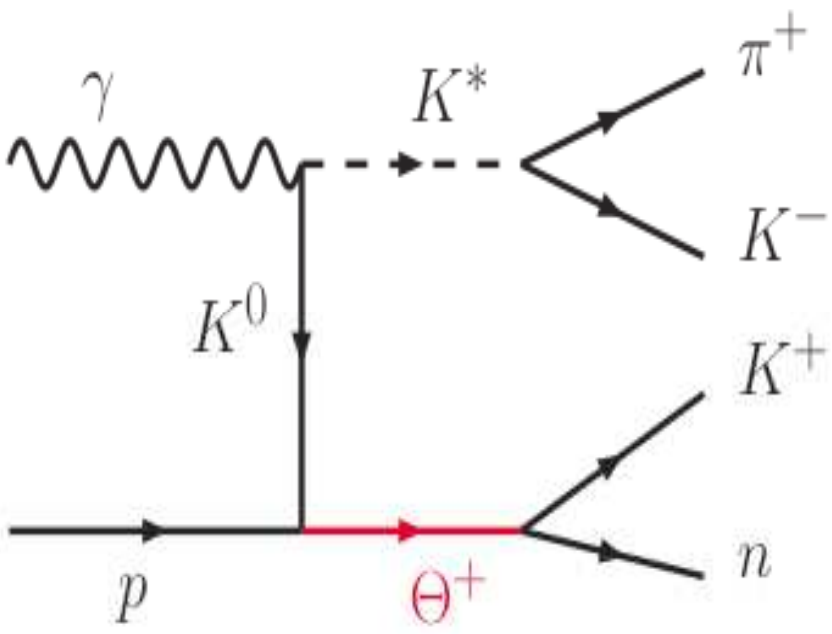
But what about the strangeness?

- In previous scenario it is not fixed
- Proton can couple to K^0 and $\bar{K}^0$
- Therefore it could be also excited Σ^*
- One can argue that in this case Σ^* should also manifest in pK^- channel, but this will be still indirect argument
- Although narrow width will also be argument in favor of pentaquark

Another interference?

$$\gamma + p \to \phi + \Delta^+ \qquad \gamma + p \to K^{*0} + \Theta^+$$





Here if one sees a peak of Θ^+ then it will be manifestly exotic $uudd\bar{s}$

Summary and Outlook

- Experimental evidence for the pentaquark is under serious doubt
- We believe that the problem still is not resolved
- New experiments and/or analysis are needed
- Interference between strong known subprocesses and unknown states might dramatically increase sensitivity of experiment
- We need to develop criteria for the claim of discovery when existence of unknown states are challanged both from theory and experiment